HYDROLOGIC CHARACTERISTICS OF ABANDONED COAL MINES USED AS SOURCES OF PUBLIC WATER SUPPLY IN MCDOWELL COUNTY, WEST VIRGINIA

By Gloria M. Ferrell

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
603 Morris Street
Charleston, WV 243015

Copies of this report can be
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CONTENTS

Page

Abstract . . . 1
Introduction . . . 1
  Purpose and scope . . . 2
  Methods of investigation . . . 3
  Description of study area . . . 4
  Mining history . . . 5
  Acknowledgments . . . 7
The Exeter Mines as sources of public water supply . . . 8
Hydrologic characteristics of abandoned coal mines . . . 10
  Occurrence and movement of ground water at mines . . . 10
  Recharge to Exeter Mines . . . 12
  Ground-water levels . . . 13
    Fluctuations . . . 13
    Response to pumping . . . 15
  Storage and availability of mine water . . . 18
  Quality of mine water . . . 18
    Factors affecting water quality . . . 25
    Changes in chemical quality caused by development of mine as a water supply . . . 29
Summary . . . 36
References cited . . . 37

ILLUSTRATIONS

Page

Figure 1. Map showing location of study area in McDowell County, West Virginia 2

2. Map showing wells, stream-gaging station and extent of mining in the Pocahontas Nos. 3 and 4 coal seams 3

3. Generalized stratigraphic column of principal surficial geologic units in north-central McDowell County, West Virginia 4

4. Schematic diagram of wells and shafts in relation to Exeter Mines 6

5. Diagram of a hypothetical room and pillar mine map 6

6. Map showing areal extent of mines in the Pocahontas Nos. 3 and 4 coal seams adjacent to the Exeter Mines 7

7 - 8. Graphs showing:

7. Monthly water withdrawals from the Hemphill coal shaft, July 1987-July 1989 8

8. Monthly metered withdrawals measured by the Welch Water Department, July 1984-July 1989 10

9. Diagram of generalized geologic section showing features of stress-relief fracturing 11

10. Block diagram of generalized geologic section showing features of stress-relief fracturing 11

11. Diagram of fractures related to mine roof collapse 12

12. Graph showing annual precipitation at Gary, West Virginia, 1977-87 12

13. Hydrograph showing water levels in the Hemphill coal shaft, 1977-87 13

14. Hydrograph showing water levels in the Hemphill coal shaft, July 1987-July 1989 14

15. Graph showing weekly precipitation at Hemphill, West Virginia, July 1987-July 1989 14

16. Hydrograph showing water level in the Hemphill coal shaft, June 15, 1988 15

17. Trilinear diagram of ionic composition of water samples from the Exeter Mines and the Tug Fork 27

18. Graph showing variation in specific conductance with depth in water from the Hemphill air shaft 28

ILLUSTRATIONS--Continued

Page

Figures 19 - 26. Graphs showing concentrations in water from the Exeter Mines for:

19. Dissolved sodium 30
20. Dissolved chloride 30
21. Dissolved calcium 31
22. Dissolved sulfate 31
23. Dissolved magnesium 32
24. Dissolved solids 32
25. Dissolved iron 33
26. Dissolved manganese 33

27 - 29. Graphs showing concentrations in water from well 3, April through August 1976 for:

27. Dissolved sodium and choride 34
28. Alkalinity and dissolved solids 34
29. Dissolved iron and manganese 35

TABLES

Page

Table 1. Descriptions of the Welch Water Department wells and the Hemphill coal shaft 9

2. Precipitation, water levels, and volume of water withdrawn for selected periods at the Hemphill coal shaft 16

3. Chemical analysis of water from well 3, April through August 1976 19

4. Chemical analysis of water from the Hemphill coal shaft, March 19, 1975, and November 8, 1977 19

5. Chemical analysis of water from the Exeter Mines for: 20

5a. Well 3 20

5b. Well 5 21

5c. Hemphill Coal Shaft 22

6. Source and significance of selected dissolved mineral constituents and physical properties of ambient waters 23

7. Summary of concentrations of selected constituents and physical characteristics of ground water from the Pottsville Group by well depth 26

HYDROLOGIC CHARACTERISTICS OF ABANDONED COAL MINES USED AS SOURCES OF PUBLIC WATER SUPPLY IN MCDOWELL COUNTY, WEST VIRGINIA

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ABSTRACT

This report presents the results of a study by the U.S. Geological Survey, in cooperation with the West Virginia Governor's Office of Community and Economic Development, the West Virginia Geological and Economic Survey, and the city of Welch, to describe the hydrologic characteristics of coal mines in West Virginia. The primary source of water supply for the city of Welch and the communities of Hemphill and Capels in McDowell County, West Virginia, is from the Exeter Mines, which are flooded and abandoned mines in the Pocahontas Nos. 3 and 4 coal seams. The Exeter Mines were abandoned in 1949.

Precipitation infiltration, inflow of surface water from the Tug Fork, and inflow of ground water from nearby mines and overlying strata (through fractures and uncased wells and shafts) are likely sources of recharge to the Exeter Mines. Rates of withdrawal during the study period ranged from about 1.6 to 1.8 Mgal/d (million gallons per day), whereas the maximum withdrawal rate needed to keep the mines dry during active mining was 1.0 Mgal/d. This increase in withdrawal rate indicates that recharge to the mines has increased since active mining ceased. The increased recharge to the mines probably is because of increased infiltration rates and inflow from nearby mines.

The combined void space created by mining in the Pocahontas Nos. 3 and 4 seams could contain about 3.1×10^9 gallons of water. Although subsidence fracturing and roof falls could have decreased void space in the mines, the corresponding increase in void spaces in the overburden could result in a combined volume nearly equal to the volume of coal that was removed during mining. Some additional storage is present in the voids formed by natural fractures and intergranular spaces in the rock that overlies the mine.

Water levels in the mine were monitored from July 1987 through September 1989. From October 1987 through April 1988, water levels in the mine rose more than 50 feet. This rise in water levels appears to be associated with the abandonment and subsequent flooding of nearby mines. Similarities in water-level fluctuations in wells that tap various parts of the Pocahontas No. 4 seam indicate a large degree of hydraulic connection within the mine.

The quality of water from the Exeter Mines changed when water levels rose; changes included increases in concentrations of sodium and chloride and decreases in concentrations of calcium and sulfate. These changes appear to be primarily associated with decreased recharge from the Tug Fork, when mine water levels rose. Water quality also changed when residence time of water in the mines increased, when water levels in nearby mines became higher than those in the Exeter Mines, and when the outflow of water from the Exeter Mines to these mines ceased.

INTRODUCTION

Coal has played a major role in the economy of West Virginia since the late 1800's. In 1980, there were an estimated 1.6 million acres of abandoned underground mines in the State (Lessing and Hobba, 1981). When below-drainage mines (mines at an altitude below that of the nearest perennial stream) are abandoned, they gradually fill with water, and the voids created by removal of coal serve as reservoirs for ground-water storage. In some areas, subsidence and vertical fracturing associated with mining have increased the permeability of the rock that overlies the mines, thereby increasing the rate of ground-water recharge. Active and abandoned coal mines are used as sources of water supply for more than 70 cities, towns, and communities in West Virginia. These coal mines are important potential sources of public water supply in many parts of the State where the quantity of other ground-water sources is insufficient for public supply, and where the quality of surface-water resources is commonly unsuitable for human consumption.

Although large quantities of water are available from underground mines, many public water suppliers have experienced difficulties in obtaining dependable water supplies from coal mines because of erratic fluctuations in the quantity and chemical quality of the water. Because coal mines respond differently to pumping and recharge than do natural ground-water systems, an improved understanding of the hydrologic characteristics of underground mines is needed.

In 1984, the U.S. Geological Survey (USGS), in cooperation with the West Virginia Governor's Office of Community and Economic Development, the West Virginia Geological and Economic Survey, and the city of Welch, began an evaluation of hydrologic characteristics of several coal mines in West Virginia, with respect to their suitability for public water supply. Some of these mines, the Exeter Mines, are located northwest of the city of Welch, in McDowell County, in southern West Virginia (fig. 1). The study area is in the low-sulfur coalfields and includes the area that overlies and is adjacent to the Exeter Mines in the Pocahontas Nos. 3 and 4 coal seams. Surface mining of coal seams that overlie the Pocahontas Nos. 3 and 4 seams covers much of the study area.

Purpose and Scope

This report describes the hydrologic characteristics of the Exeter Mines, in southern West Virginia, with respect to their suitability for water supply. Information in this report was obtained from July 1987 through September 1989. The report describes the occurrence and flow of ground water at the mines, recharge to the mines, ground-water levels, storage and availability of mine water, and quality of mine water. Seasonal fluctuations in ground-water levels, ground-water level response to pumping, and estimates of the volume of storage and practical sustained yield of the mines are also given.

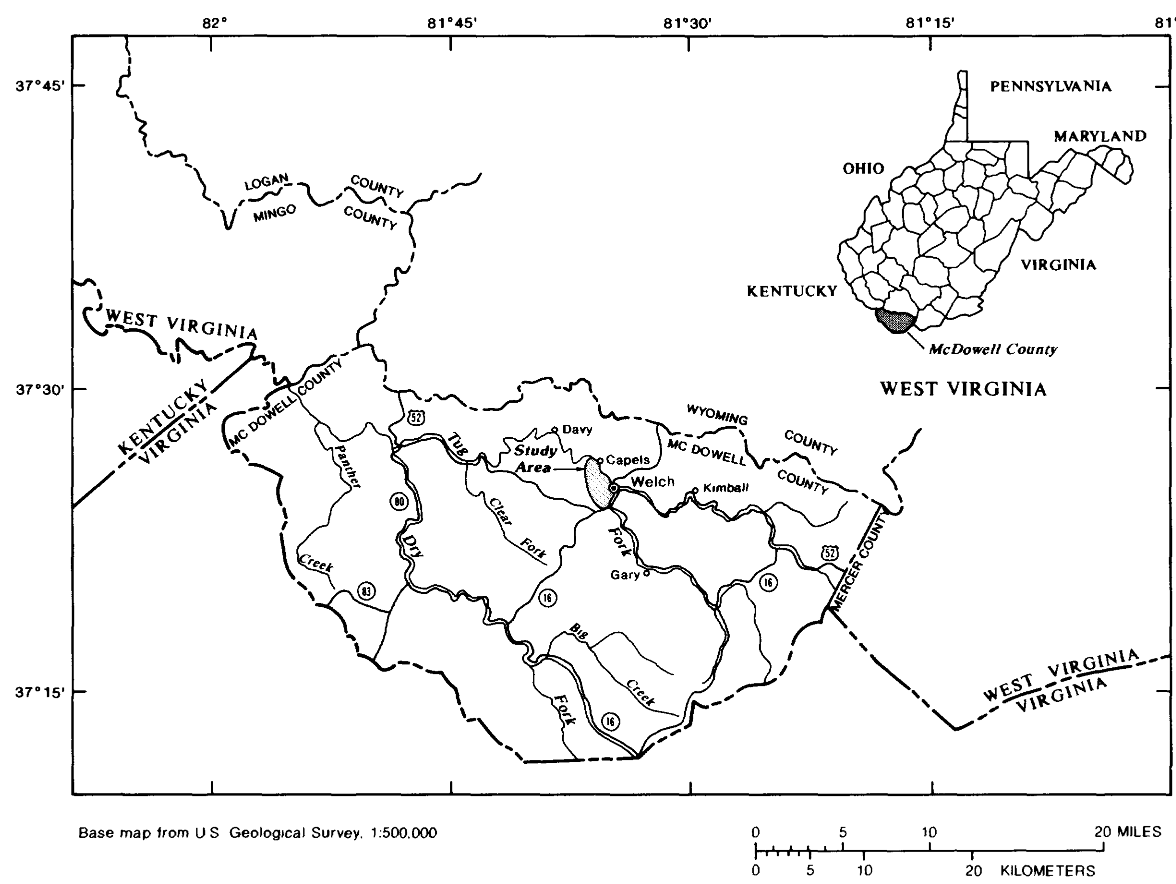

Figure 1.--Location of study area in McDowell County, West Virginia.

Methods of Investigation

Water-level, pumpage, precipitation (including snow and rain), and water-quality data were collected at the study sites. Water levels were monitored at two sites -- the Hemphill coal shaft, and well 2, an abandoned well formerly used by the Welch Water Department (fig. 2). Water-level recorders were installed at these sites in June 1987. Well 2 and the Hemphill coal shaft tap the Pocahontas Nos. 3 and 4 coal seams. Water levels could not be measured at other wells because of obstruction by pumps. Surface elevations of the water-level monitoring sites and other wells that tap the Exeter Mines were determined by surveying. Water-level data obtained for periods before the study were provided by the Welch Water Department.

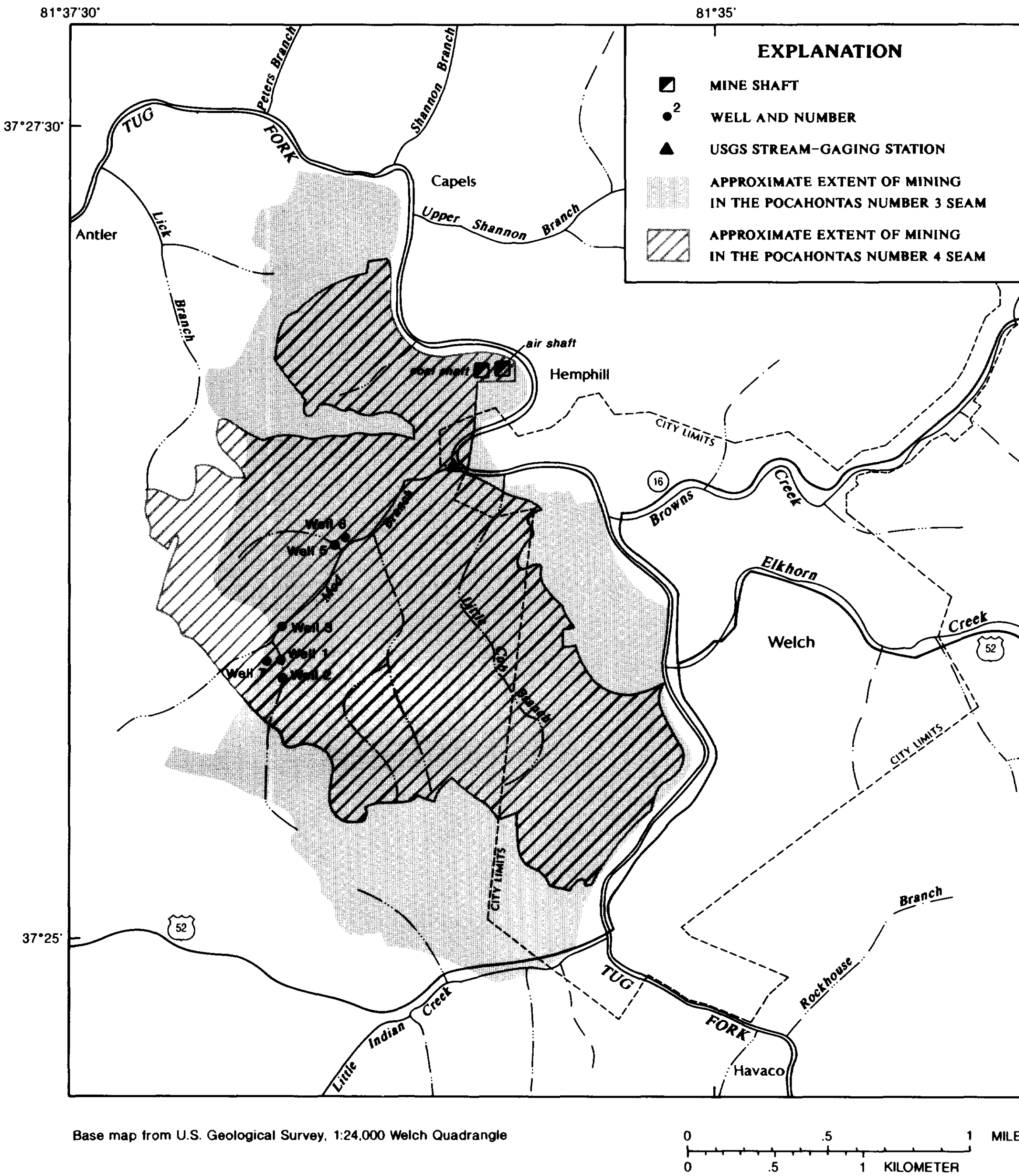

Figure 2.--Wells, stream-gaging station, and extent of mining in the Pocahontas Nos. 3 and 4 coal seams.

Pumpage records were obtained from digital induction-time totalizers installed at the Hemphill coal shaft and at the Welch Water Department well 6. Pumpage information was supplemented with records from the Welch Water Department. Pump ratings were provided by personnel from the Welch Water Department and the McDowell Water Company.

Precipitation data were obtained in Hemphill from a tipping-bucket rain gage that was installed on the USGS streamflow gage at Tug Fork at Welch, in September 1987 (fig. 2). Precipitation records for periods prior to September 1987 were obtained from the National Oceanic and Atmospheric Administration precipitation site at Gary, W. Va., located about 5 mi southeast of the study area.

Water samples were collected from wells 3 and 5, which are used by the Welch Water Department, and from the Hemphill coal shaft, which is used by McDowell Water Company to supply the communities of Hemphill and Capels. Seven water samples were collected from well 5 and the Hemphill coal shaft. Six samples were collected from well 3. The water samples were analyzed for major ions and trace metals by the USGS Water-Quality Laboratory in Denver, Colo. Measurements of specific conductance, pH, temperature, dissolved-oxygen concentration, and alkalinity were made by USGS personnel from the West Virginia District. Water-quality data for the Tug Fork at Welch were obtained from the files of the USGS. Data for water samples collected and analyzed by the West Virginia Department of Health also were used to evaluate the quality of water from the mines.

Description of Study Area

The study area is located in the Appalachian Plateau physiographic province and is characterized by steep hillsides and narrow, V-shaped valleys (Fenneman, 1938). Little flatland is present. The area is primarily forested. Soil thickness is typically less than 12 in., and soil can be virtually absent in surface-mined areas. Surface altitudes in the study area range from about 1,270 ft above sea level along the Tug Fork, to 2,260 ft above sea level along ridges overlying the Exeter Mines.

The area is underlain by the New River and Pocahontas Formations of the Pottsville Group of the Pennsylvanian system. Regional dip is northwestward at less than 100 ft/mi (Rehbein and others, 1981). No major geologic structures are present, though slight localized folds are found. A generalized stratigraphic column is shown in figure 3. The New River Formation primarily consists of alternating layers of sandstone, shale, and coal with interbeds of clay. It also includes the Sewell and Welch coals, which have been mined by underground and surface methods in the study area. The Pocahontas Formation underlies the New River Formation and is lithologically similar. The Pocahontas Formation includes the Pocahontas Nos. 3 and 4 coal seams, which have been mined in the study area by underground methods.

The Pocahontas Nos. 3 and 4 coal seams dip to the northwest at about 70 ft/mi in the study area (Hennen and Gawthrop, 1915). The Pocahontas No. 3 seam lies about 60 ft below the base of the Pocahontas No. 4 seam. The nearest outcrop of the Pocahontas No. 3 seam is at Kimball, W. Va., about 5 mi southeast of the study area (fig. 1). Altitudes of the Pocahontas No. 3

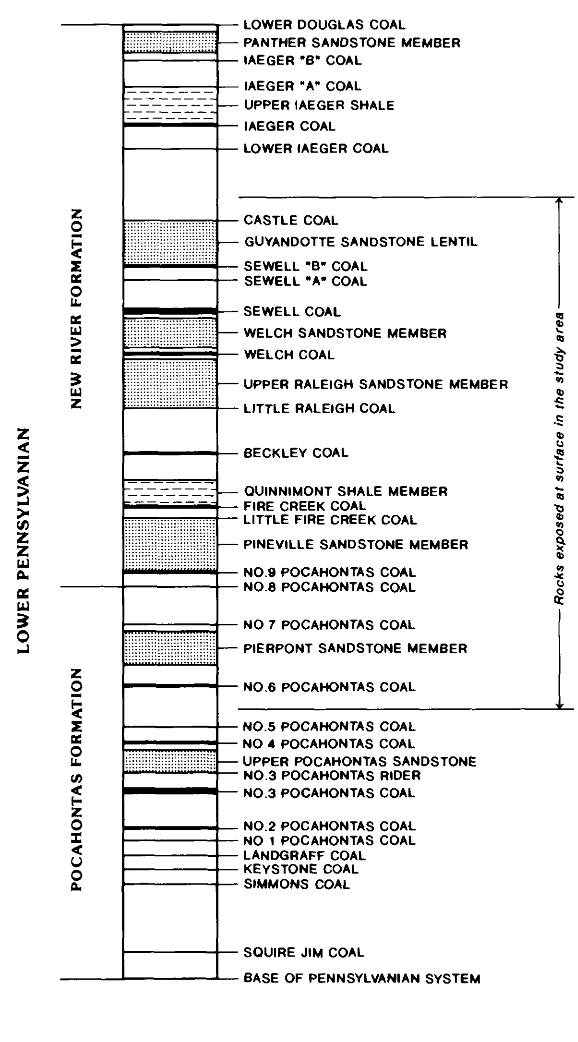

Figure 3.--Generalized stratigraphic column of principal surficial geologic units in north-central McDowell County, West Virginia.

seam in the Exeter Mines range from about 950 ft above sea level along the southeastern edge of the mine, to about 890 feet above sea level along the northwestern edge of the mine. The floor of the mine is nearly level with a gentle slope to the northwest (Leo Signiago, Riverside Coal Company, oral commun., 1989). Thickness of the Pocahontas No. 3 coal seam ranges from about 65 in. along the eastern edge of the mine, to about 35 in. along the western edge of the mine, averaging about 60 in. The thickness of the coal seam decreases along the southern and western edges of the mine and the thickness of "partings" (layers of non-coal material, such as slate, shale, or sandstone, that are interbedded with coal) increases. Because of the decreased thickness of the coal and the increased thickness of the partings, it became unprofitable to continue mining in this direction, and the westward direction of mining ceased. The approximate areal extent of mining in the Pocahontas No. 3 seam is 2.8 mi^2 (fig. 1).

The altitude of the base of the Pocahontas No. 4 coal seam ranged from about 1,000 ft above sea level along the southeastern edge of the mine, to about 960 ft above sea level in the northwestern part of the mine. Like the underlying Pocahontas No. 3 mine, the floor of the Pocahontas No. 4 mine is nearly level with a gentle northwestward slope, with only minor localized deviations from regional dip (Leo Signiago, Riverside Coal Company, oral commun., 1989). The thickness of the Pocahontas No. 4 seam ranged from 73 in. in the southeastern part of the mine, to less than 40 in. along the western edge of the mine. Average thickness of the Pocahontas No. 4 seam was about 60 in. Decreased thickness of the Pocahontas No. 4 seam and the increased thickness of sandstone partings resulted in the end of mining in the westerly and southwesterly directions. Along the southwestern edge of the mine, the thickness of the Pocahontas No. 4 coal seam decreases and the coal seam is replaced by sandstone. The approximate areal extent of mining in the Pocahontas No. 4 seam is 1.9 mi^2.

Mining History

More coal has been mined in McDowell County than in any other county in West Virginia. From 1883 through 1989, more than 1.46 billion short tons of coal were mined (West Virginia Division of Energy, 1990). In McDowell County, the Pocahontas Nos. 3 and 4 seams characteristically contain low-volatile, low-sulfur (less than 1 percent total sulfur), high-grade metallurgical coal (Smith and others, 1977).

The Exeter Mines were opened in 1929 and abandoned in 1949. The Pocahontas Nos. 3 and 4 seams were mined concurrently. The entrance to the mines was a 365-ft vertical shaft referred to in this report as "the Hemphill coal shaft" (fig. 4). A second shaft, the Hemphill air shaft, extended from land surface to the Pocahontas No. 4 seam and was used for ventilation. A sloping shaft between the Pocahontas Nos. 3 and 4 seams was used to haul coal and equipment between the seams. A vertical shaft between the seams was used for ventilation (fig. 4).

Coal in the Exeter Mines was removed by the "room-and-pillar" method. The percentage of coal removed by this method of mining typically ranged from 50 to 80 percent. In "room-and-pillar" mining, a series of parallel entries, or tunnels, are dug into the coal. These are referred to as the "main entries," or "mains." Blocks of coal are left between the main entries. Additional entries are driven at right angles to the main entries. The rooms from which most of the coal is mined are at right angles to these additional entries. Pillars of coal are left along the entries and between the rooms for roof support. These pillars are commonly removed before the mines are abandoned. A diagram of a typical room-and-pillar mine is shown in figure 5.

The roof of the Pocahontas No. 3 mine consisted of shale ranging in thickness from 0 to 24 in., overlain by a 2- to 4-in. coal seam. This thin, overlying coal seam weakened the roof, and, as a result, roof falls were common. The roof and floor of the Pocahontas No. 4 mine consisted of a fine-grained sandstone and few roofs fell (Leo Signiago, Riverside Coal Company, oral commun., 1989). While pillars were being removed in the Pocahontas No. 4 seam, roof falls were common in the underlying Pocahontas No. 3 mine. Only about 50 percent of the coal in the Pocahontas No. 3 mine was removed because of dangerous roof conditions and the presence of thick partings. Pillars were removed in only a few parts of the Pocahontas No. 3 mine. About 80 percent of the coal in the Pocahontas No. 4 mine was removed and complete pillar removal was achieved (Leo Signiago, Riverside Coal Company, oral commun., 1989).

During active mining, the mines were dewatered by continuous pumping at a rate of 400 to 700 gal/min (0.58 to 1.0 Mgal/d). At these rates, the mines were fairly dry during active mining. Most of the water that entered came from the sides of the shafts and from the workings along the river. Little water was observed entering the mines from the strata underlying small streams such as Mod Branch. No water was observed entering from the mine roofs or along the coal seams, except in the vicinity of Tug Fork.

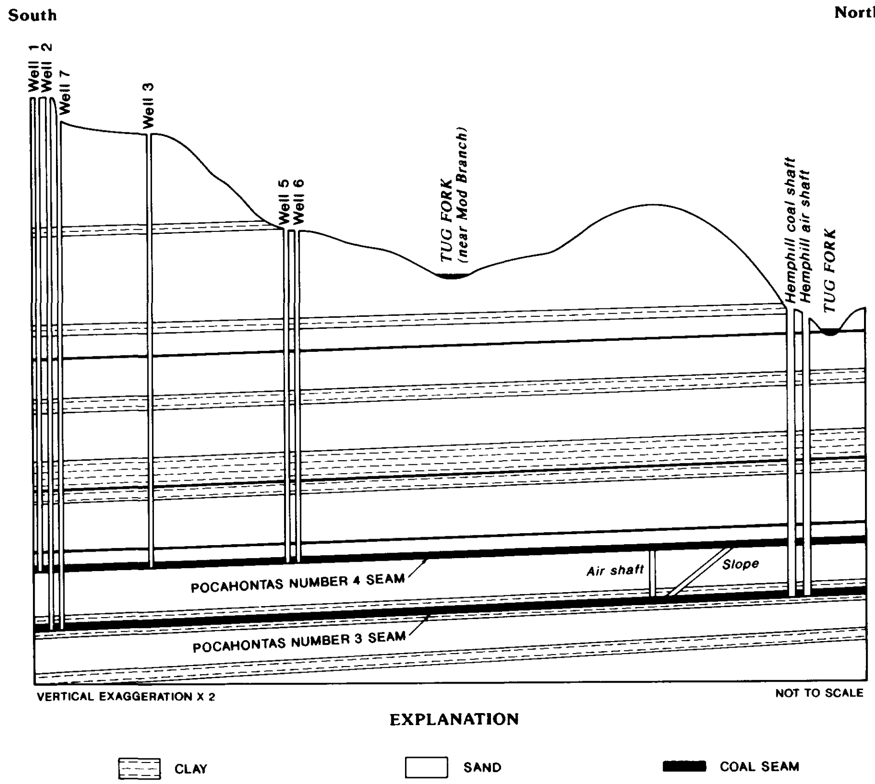

Figure 4.--Schematic diagram of wells and shafts in relation to Exeter Mines.

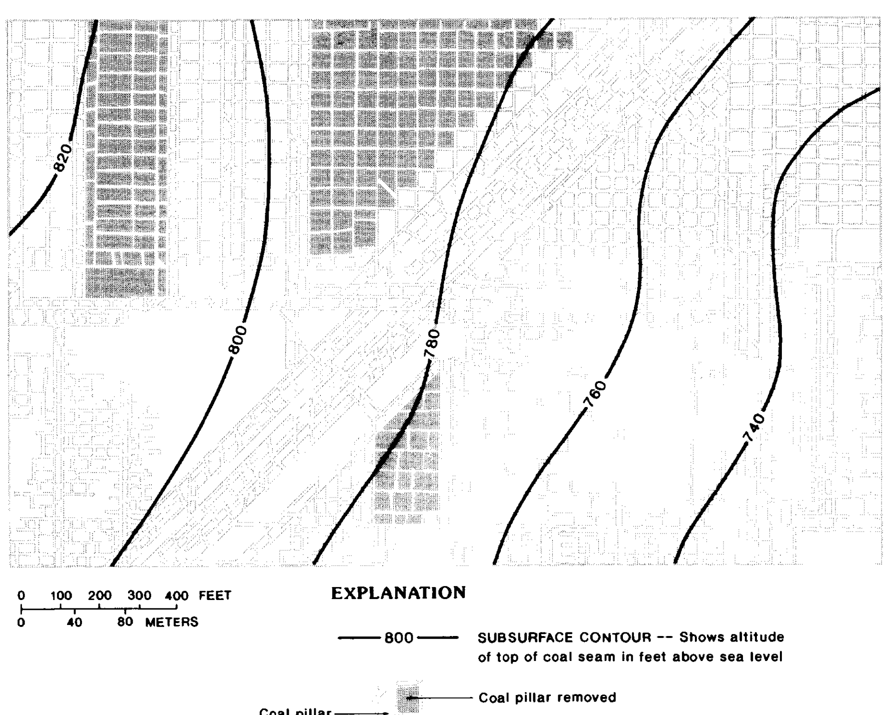

Figure 5.--Diagram of a hypothetical room and pillar mine map.

According to mine maps in the files of the West Virginia Geological and Economic Survey, the Exeter Mines are separated from adjacent coal mines in the Pocahontas Nos. 3 and 4 seams by a barrier of coal about 500 ft wide. Other mines in the Pocahontas Nos. 3 and 4 seams are located along the northeastern, eastern, and southern boundaries of the Exeter Mines (fig. 6). There has been no mining in the Pocahontas No. 3 seam northwest of the Exeter Mines. Most of the adjacent mines were active until the mid-1980's.

Acknowledgments

The author wishes to thank Donald Stroupe, Frazier Baker, Jr., and Estel T. Burks, plant operators for the Welch Water Department, and Foster Muncy of the McDowell Water Company, for their assistance and access to records. Information about the Exeter Mines and hydrologic and geologic characteristics of nearby mines was provided by the West Virginia Department of Energy and numerous coal and land companies. Access to mine maps and information about mining conditions was provided by Leo Signiago of Riverside Coal Company, William Swope of Swope Realty Company, and the West Virginia Geological and Economic Survey.

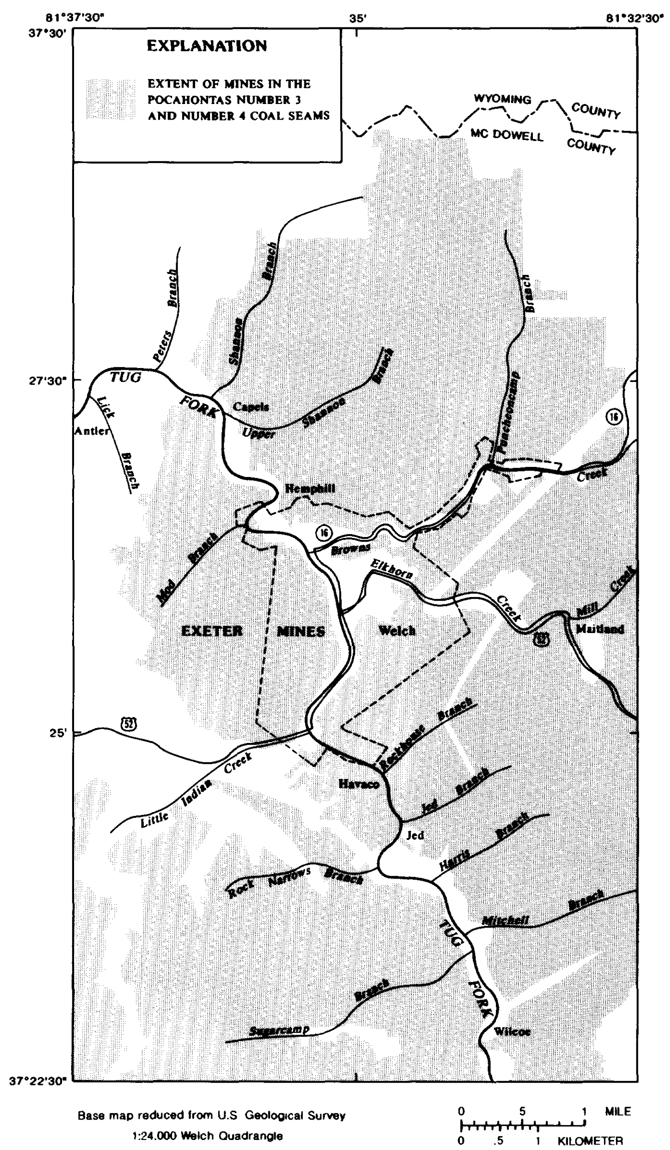

Figure 6.--Areal extent of mines in the Pocahontas Nos. 3 and 4 coal seams adjacent to the Exeter Mines.

THE EXETER MINES AS SOURCES OF PUBLIC WATER SUPPLY

The Exeter Mines are the main sources of water for the city of Welch and the communities of Hemphill and Capels. In 1989, the Welch Water Department supplied water to a population of about 4,300 (Donald Stroupe, Welch Water Department, oral commun., 1989). McDowell Water Company, which serves Hemphill and Capels, supplied water to a population of about 190 (Foster Muncy, McDowell Water Company, oral commun., 1989).

During active mining during 1929-48, water pumped from the Hemphill coal shaft supplied the community of Hemphill and has remained the water supply for this community since then. McDowell Water Company operates a submersible pump in the Hemphill coal shaft. During 1987-89, estimated pumpages were about 360 gal/min and the duration of pumping ranged from about 10 hours per day in the summer and fall, to more than 17 hours per day during the winter. In the winter, many residents leave water running to prevent pipes from freezing, which could account for increased water use during winter months (Foster Muncy, McDowell Water Company, oral commun., 1989). Water service to the communities of Hemphill and Capels is unmetered. During the study, estimated withdrawals from the coal shaft ranged from 7.1 to 10.1 Mgal per month (fig. 7).

Welch began using the Exeter Mines as a source of water in 1976 and has drilled six wells into the mines since 1976 (fig. 4). Four of the six wells tap only the Pocahontas No. 4 mine. Two of the wells were drilled through the Pocahontas No. 4 mine and into the Pocahontas No. 3 mine. Available information about these wells is listed in table 1.

The yields of wells 1, 2, and 3, drilled at or above the elevation of the water plant, were not sufficient to supply the needs of Welch. This could have been because of the large vertical distance (300 to 350 ft) that the water had to be lifted by the submersible pumps in these wells. During the course of this study, water pumped from wells 5 and 6 supplied Welch. These

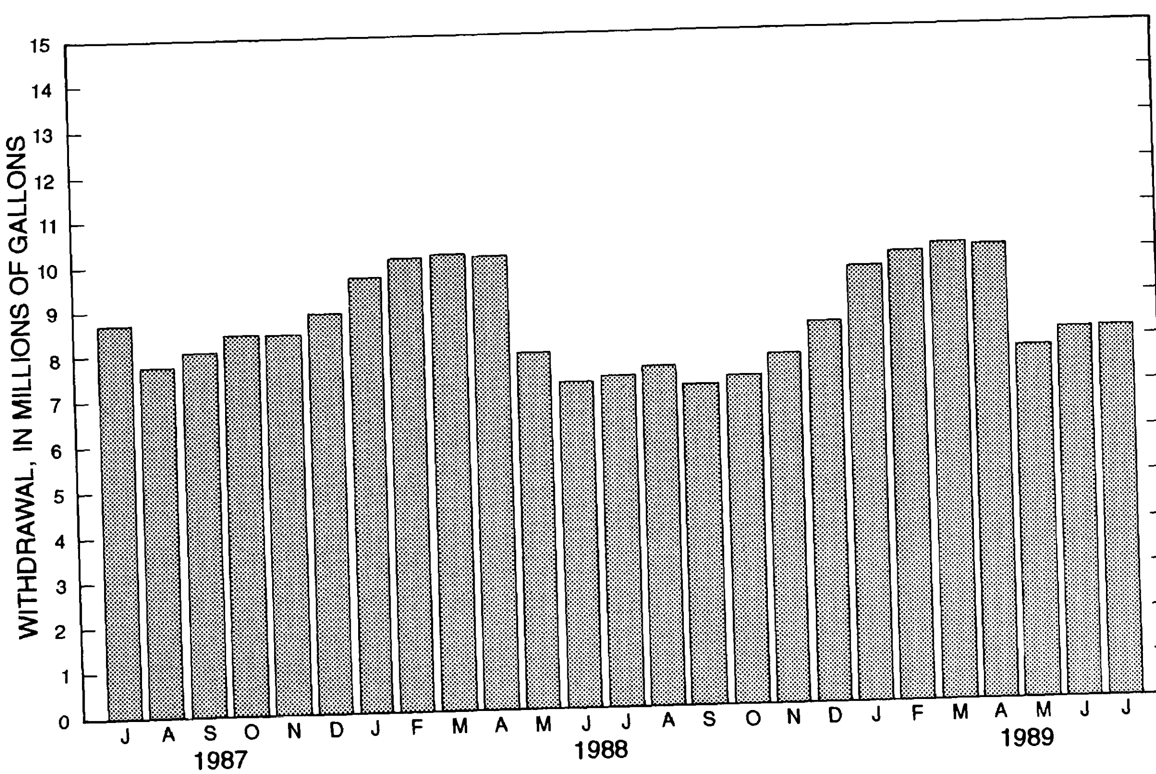

Figure 7.--Monthly water withdrawals from the Hemphill coal shaft, July 1987-July 1989.

Table 1.--Descriptions of the Welch Water Department wells and Hemphill Coal Shaft

[ft = feet; in. = inches]

Well no.	Surface elevation (ft above sea level)	Reported depth (ft below land surface)	Diameter (in.)	Length of casing (ft)	Type of pump	Elevation of pump intake (ft above sea level)
1	1,570	575	8	20	None	--
2	1,570	630	8	20	None	--
3	1,522	535	8	20	Submersible	1,179
5	1,400	436	10	20	Submersible	1,036
6	1,400	400	10	20	Submersible	1,087
7	1,540	610	10	610	Submersible	929
Coal shaft	1,299	365	--	--	Submersible	1,165
Air shaft	1,292	300	--	--	None	--

wells are about 15 ft apart and are about 1,400 ft above sea level. Both of these wells tap only the Pocahontas No. 4 mine. The combined pumpage for wells 5 and 6 is about 590 gal/min, with the use of a booster pump to help pump the water from the wellhead up to the water plant. Without the booster pump, the pumpage is about 270 gal/min.

Well 7 was drilled through the Pocahontas No. 4 seam and into the Pocahontas No. 3 mine. This well penetrated an unmined area or a pillar of coal in the Pocahontas No. 4 mine (Donald Stroupe, Welch Water Department, oral commun., 1989). A turbine pump, capable of pumping 600 gal/min, was installed in this well. The yield of this well was insufficient to allow continuous operation of the pump, however.

From July 1987 through 1989, the average pumpage of the Welch Water Department was about 1.4 Mgal/d. The maximum pumpage was about 1.7 Mgal/d. At times, the water supply has been supplemented by a small reservoir near the water plant. The monthly metered outflows from the Welch water plant from July 1984 through August 1989 are shown in figure 8. These outflow volumes do not include water used in the plant, which was estimated to be 80,000 gal/d (Donald Stroupe, Welch Water Department, oral commun., 1989).

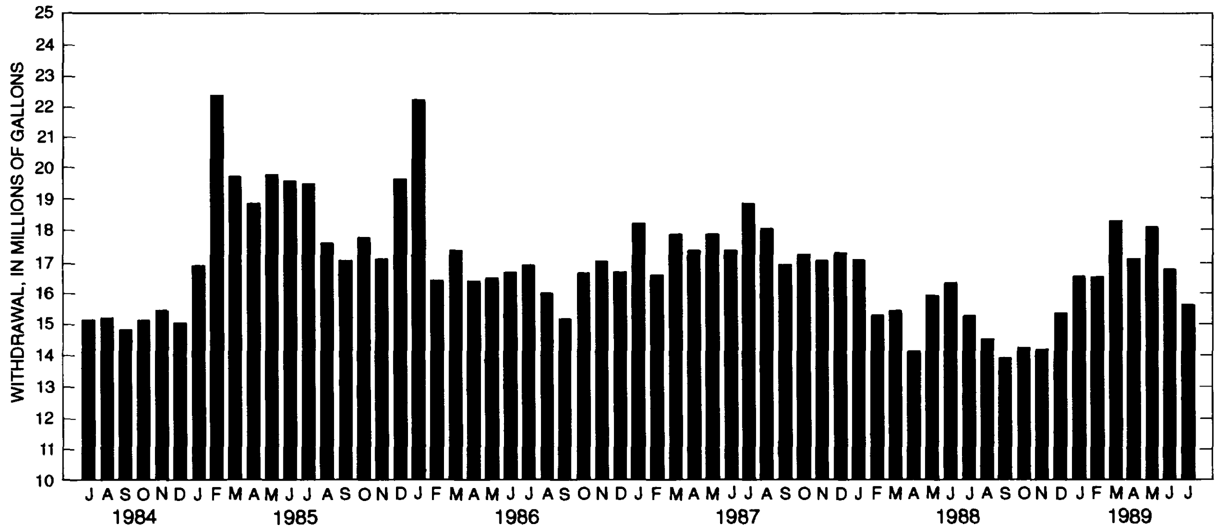

Figure 8.--Monthly metered withdrawals measured by the Welch Water Department, July 1984-July 1989.

HYDROLOGIC CHARACTERISTICS OF ABANDONED COAL MINES

The availability of water from flooded underground coal mines is determined by the presence and movement of ground water in the overburden and surrounding rock, nearby mining activities, the amount of precipitation and other sources of recharge, and characteristics of the mine. Underground mining can alter the hydrologic characteristics of overlying and surrounding areas. Removal of coal creates large voids and can weaken overlying strata. This removal could result in fracturing of overlying strata and increased vertical permeability. During active mining, dewatering of mines also can dewater the overlying strata and deplete ground-water supplies in these strata. After abandonment and flooding of mines, openings to the mines, such as shafts and tunnels, can become outflow points for ground water.

Occurrence and Movement of Ground Water at Mines

The study area is overlain primarily by consolidated rocks. Unconsolidated deposits are absent, except for thin layers along the Tug Fork. Intergranular spaces in the consolidated rocks have been filled with cementing materials and are small and poorly interconnected. Ground water in the consolidated rocks of this area is primarily stored and transmitted through a system of fractures. Studies in unmined areas of southern West Virginia have shown that ground water is stored and flows primarily in stress-relief fractures (Wyrick and Borchers, 1981). Stress-relief fractures appeared where erosion of overlying strata has reduced the compressional forces acting on underlying strata. As overlying strata eroded, compressional forces on the rocks that underlie the valley floor decrease. This decrease in compressional forces acting on the valley floor has caused bedding-plane separation (figs. 9 and 10). Bedding-plane separations are not present in the strata that underlie the hills, because these strata are under compression.

Vertical fractures have formed along the sides of valleys in response to slumping of valley walls as a result of erosion. Most of the ground-water flow in the consolidated rocks in southern West Virginia is through bedding-plane separations in valley floors and through vertical fractures along valley walls. The fracture systems along valley walls are rarely saturated and are conduits for transmission of precipitation into the bedding-plane separations in valley floors. Fractures that store and transmit significant quantities of ground water are rarely located under hilltops and, as a result, only small amounts of ground water generally are available from the rocks underlying hilltops.

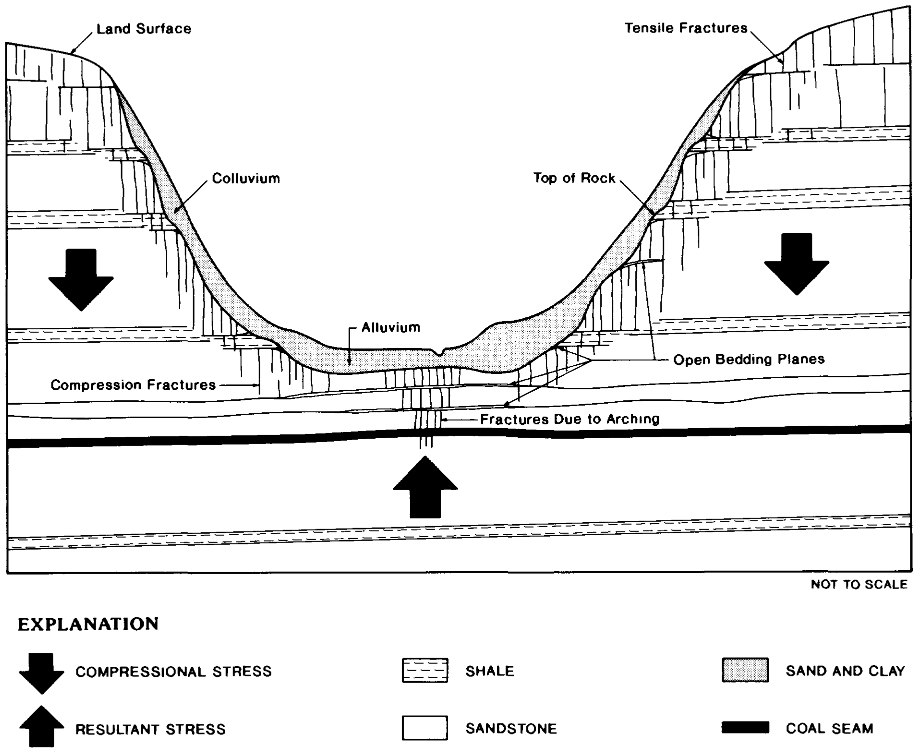

Figure 9.--Diagram of generalized geologic section showing features of stress-relief fracturing.

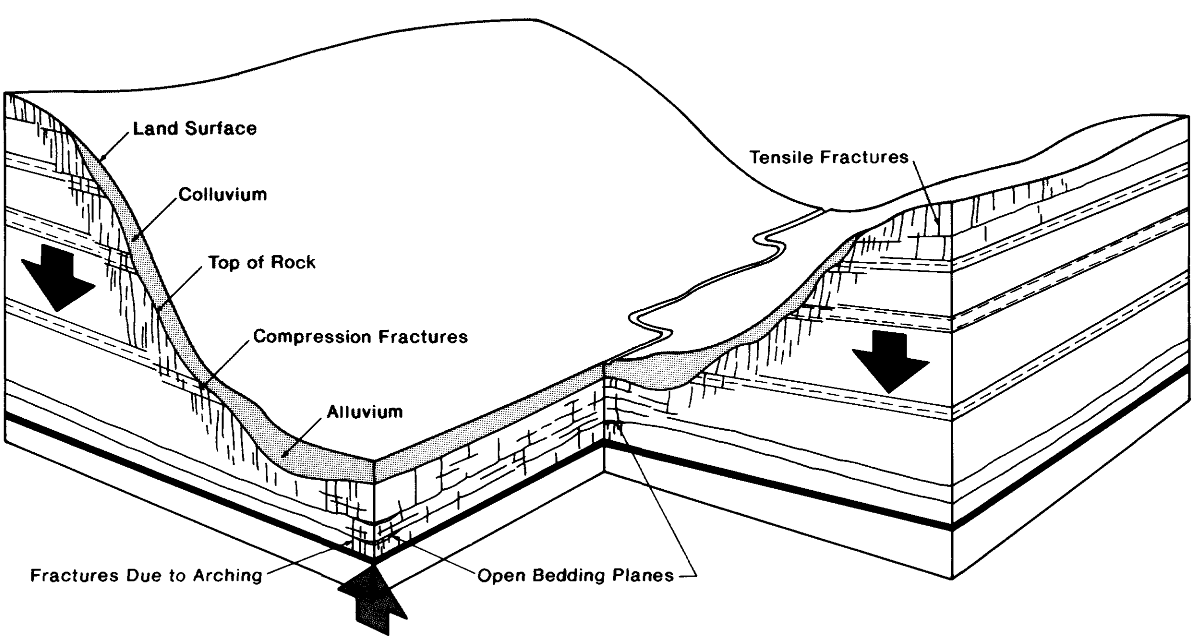

Figure 10.--Block diagram of generalized geologic section showing features of stress-relief fracturing.

Vertical fractures and voids created by mining alter the storage and movement of ground water. The underground voids created by coal mining are capable of storing and transmitting large volumes of water. In many areas of West Virginia, collapse of overburden into these voids has caused fracturing and increased the vertical permeability of overlying strata (fig. 11) (Hobba, 1981). Increased vertical permeability has resulted in increased recharge rates. Studies of rainfall-runoff relations at mined and unmined sites in McDowell County have indicated that the amount of runoff at mined sites is about half that at unmined sites (Scott, 1984).

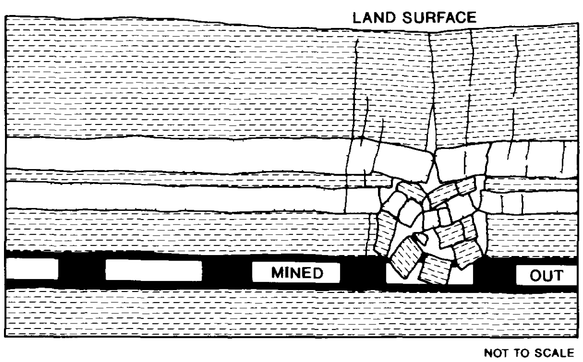

Figure 11.--Diagram of fractures related to mine roof collapse.

Active mining requires dewatering the mines; for below-drainage mines, withdrawal of large volumes of water could be necessary to make conditions suitable for mining. Dewatering mines changes flow paths and storage of ground water for a large area. Discharge permits for the adjacent mines along the north and east of the Exeter Mines indicate a pumpage of 3.9 Mgal/d during active mining (Kenneth Politan, West Virginia Department of Energy, oral commun., 1990). These mines were closed and dewatering activities were terminated in 1984. Dewatering and closure information for the mines south of the Exeter mines was unavailable.

When dewatering activities cease, below-drainage mines gradually fill with water. The rate of filling is affected by several factors, including permeability of the overburden, size of the mine, and sources of recharge. During wet periods, the rate of filling is greater than during dry periods. Mines that require large amounts of pumpage for dewatering tend to fill with water in less time than mines that require small amounts of pumpage for dewatering. Complete flooding of mines in the Pocahontas Nos. 3 and 4 seams near the study area typically took 3 to 4 years after termination of dewatering activities (Jackie Taylor, West Virginia Department of Energy, oral commun., 1989).

Recharge to Exeter Mines

Precipitation infiltration, inflow of surface water from the Tug Fork, and inflow of ground water from nearby mines and overlying strata (through fractures and uncased wells and shafts) are likely sources of recharge to the Exeter Mines. Rates of withdrawal during the study period ranged from about 1.6 to 1.8 Mgal/d, whereas the maximum withdrawal rate needed to keep the mines dry during active mining was 1.0 Mgal/d. This increase in withdrawal rate indicates that recharge to the mines has increased since active mining. The increased recharge to the mines probably is because of increased infiltration rates and inflow from nearby mines.

Mean annual precipitation during 1951-80 at Gary, W. Va., which is about 5 mi south of the study area, was 41 in. (National Oceanic and Atmospheric Administration, 1982). Annual precipitation at Gary was 36 in. in 1987 and 34 in. in 1988 (National Oceanic and Atmospheric Administration, 1987-88) (fig. 12). Ground water from overlying and surrounding areas

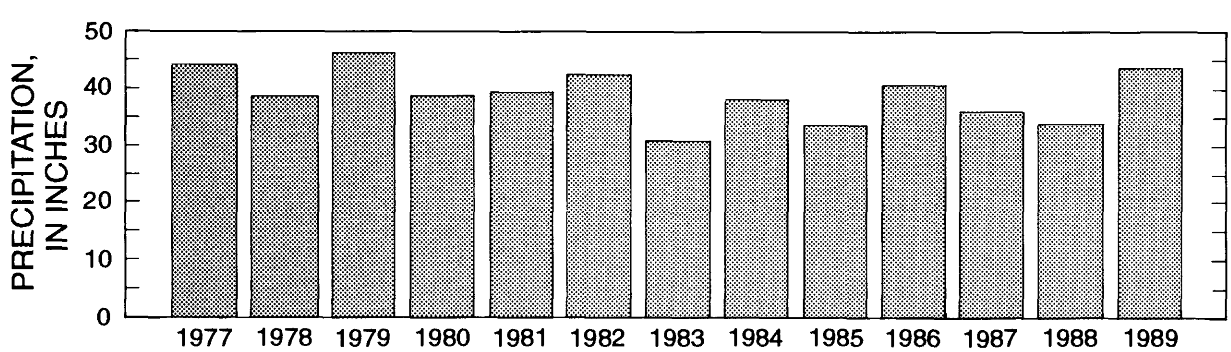

Figure 12.--Graph showing annual precipitation at Gary, West Virginia, 1977-87.

recharges the mines. Water levels in the mines rose almost instantaneously with the start of precipitation, particularly well 2. During periods of rainfall, water could typically be heard running into the well bore at well 2. Uncased wells could contribute to recharge to the mines by intercepting horizontally moving ground water. At times, increases in water levels in response to precipitation were observed in well 2 and in the coal shaft, even when the withdrawal rate exceeded 650 gal/min.

Water probably flows into the Exeter Mines from the Tug Fork through fractures under the riverbed when water levels in the mines are lower than water levels in the river. The rate of inflow probably increases as the hydraulic gradient between the river and the mines increases, and decreases as the hydraulic gradient decreases. When water levels in the mines are higher than those in the river, water from the mines could flow into the river. Pumping from the Exeter Mines typically keeps water levels in the mines below the level of water in the Tug Fork, however.

Water also can flow between the Exeter Mines and adjacent mines. When water levels in the Exeter Mines are lower than those in adjacent mines, water inflows from the adjacent mines. When water levels in the adjacent mines are at lower levels than those in the Exeter Mines, water outflows from the Exeter Mines.

Ground-Water Levels

The Welch Water Department made periodic measurements of water levels at the Hemphill coal shaft from 1977 through 1987 (fig. 13). Water levels were monitored throughout the study at the coal shaft and at well 2 (fig. 4). The coal shaft and well are 1.25 mi apart and tap the Pocahontas Nos. 3 and 4 seams. The water level in well 2 was about 10 ft higher than the water level in the coal shaft. The higher water level in the coal shaft could be because the shaft is farther from the primary points of withdrawal, wells 5 and 6, or closer to a source of recharge, such as the Tug Fork or adjacent mines, than is well 2.

Fluctuations

Water-level fluctuations at the coal shaft and at well 2 were similar. A nearly instantaneous decline in water level was observed at the coal shaft and at well 2 when pumps in wells 5 and 6 were activated. Similarly, a nearly instantaneous decline in water level was observed when the pump in the coal shaft was activated. The similarity of water-level changes in response to pumping at these sites indicates a large degree of hydraulic connection in the mine.

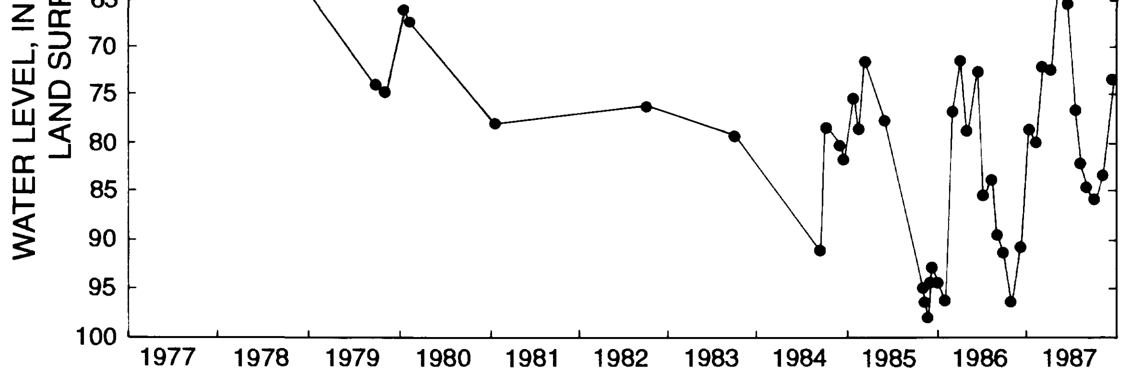

Figure 13.--Water levels in the Hemphill coal shaft, 1977-87.

During the study, water levels in the coal shaft and in well 2 increased greater than 50 ft. The hydrograph for the coal shaft from July 1987 through July 1989 is shown in figure 14. In October 1987, the water level in the coal shaft began to rise from a minimum of 88 ft below land surface (1,211 ft above sea level). By April 1988, the water level had risen to 33 ft below land surface (1,266 ft above sea level). Water levels did not change significantly during the remainder of the study, despite relatively dry conditions throughout the spring and summer of 1988 (fig. 15).

From March 1988 through July 1989, water levels in the coal shaft were higher than any measured by Welch Water Department personnel prior to this study. The rise in water level does not appear to be associated with increased amounts of precipitation (fig. 15). Precipitation from March through August 1988 was 7.5 in. below normal (for these months) at Gary, W. Va.; however, the overall decline in minimum daily water level in the coal shaft was less than 3 ft during this period. Withdrawal of water from the mines decreased slightly during the time of the water-level increase; however, increased withdrawals afterward (figs. 6 and 7) did not cause a major decline in water level.

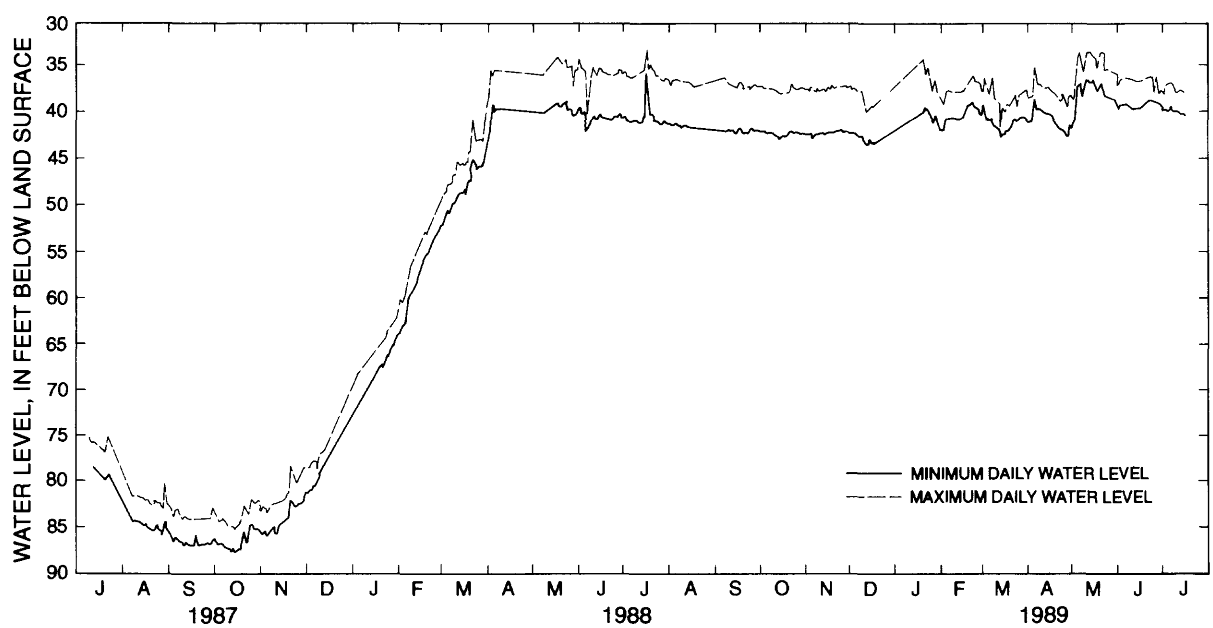

Figure 14.--Water levels in the Hemphill coal shaft, July 1987-July 1989.

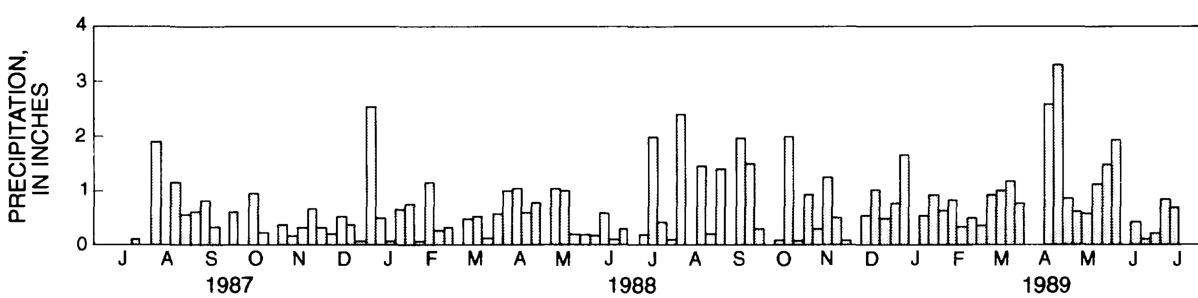

Figure 15.--Weekly precipitation at Hemphill, West Virginia, July 1987-July 1989.

Water levels in the Exeter Mines rose in conjunction with abandoning and subsequent flooding of adjacent mines in the Pocahontas Nos. 3 and 4 coal seams (fig. 6). The rise in water levels ended in March 1988, and corresponded to the time when water began to flow out of a vertical shaft at an adjacent mine northeast of the Exeter Mines, which had been abandoned in 1984 (Jackie Taylor, West Virginia Department of Energy, oral commun., 1989). The altitude of the outflow from the adjacent mine is 1,278 ft above sea level, which is higher than water levels in the Hemphill coal shaft. Elevation of land surface at the coal shaft is 1,299 ft above sea level (table 1). During the summer of 1989, the rate of flow at the adjacent mine was about 5,000 gal/min (7.2 Mgal/d) (Jackie Taylor, West Virginia Department of Energy, oral commun., 1989). Flow of water from a shaft in another abandoned mine east of the Exeter Mines also began in late 1986 or early 1987 (fig. 6). Flow from this shaft averaged about 2,000 gal/min during the study (Jackie Taylor, West Virginia Department of Energy, oral commun., 1989). It is likely that dewatering of adjacent mines during active mining and the resulting decline in water levels in the adjacent mines induced a flow of water from the flooded Exeter Mines into the active adjacent mines, thus lowering water levels in the Exeter Mines.

Before the adjacent mines became flooded, water levels in the Exeter Mines were below water levels in the Tug Fork, and significant amounts of recharge to the Exeter Mines probably came from the Tug Fork, particularly in parts of the mines that are near or underlie the river. From July to September 1987, water levels in the Exeter Mines ranged from 45 to 58 ft below the elevation of water levels in the Tug Fork. After March 1988, the month in which water began to flow from the adjacent mine, water levels in the Exeter Mines typically were only several feet lower than the water levels in the river. Under these conditions, recharge from the Tug Fork probably is reduced because of the decreased hydraulic gradient between water in the Tug Fork and water in the Exeter Mines. Because of the rise in water levels in the adjacent mine to an altitude higher than that in the Exeter Mines, the adjacent mines are a likely source of recharge to the Exeter Mines.

Response to Pumping

Water levels declined when pumping rates exceeded 650 gal/min except during periods of precipitation. When the Welch Water Department was pumping from only one well (well 6), water levels rose even with pumping from the coal shaft. A typical 24-hour water-level hydrograph for the Hemphill coal shaft is shown in figure 16. Water levels generally rose until about 6:00 a.m., when the pump in well 5 was activated. The water level declined until about 11:00 p.m., when the pump in well 5 was turned off. Small fluctuations in the hydrograph were the result of pumping from the coal shaft by the McDowell Water Company.

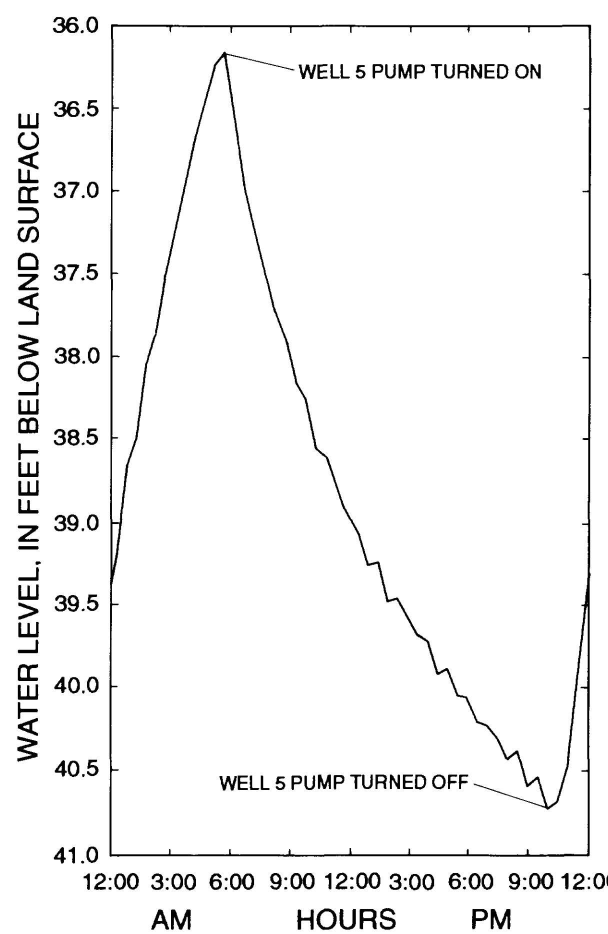

Figure 16.--Water level in the Hemphill coal shaft, June 15, 1988.

Hydrographs from the Hemphill coal shaft were evaluated to determine the amount of drawdown at various pumpages (table 2). Methods of evaluating the response of the Exeter Mines to pumping were limited because the mines were used as a water supply, and no opportunity existed for an extended period without pumping. Water was withdrawn at three sites. Water-level measurements could not be obtained at the two wells with the largest rates of withdrawal (wells 5 and 6). A constant pumping schedule enabled day-to-day comparisons of minimum daily water levels for similar pumping regimes. Four time periods were used for hydrograph analysis. One of these periods was before the rise in water levels; the other three were after the rise in water levels. During the rise in water levels, the minimum daily water level generally increased, regardless of the amount of withdrawal. An attempt was made to select periods for analysis during which the amount of precipitation was small; also, periods that had been preceded by several days of little or no precipitation were selected. Relatively few such periods existed during the study. Differences in the rate of water-level decline per volume of water withdrawn during these four periods probably are because of antecedent precipitation conditions, differences in recharge rates, differences in sources of recharge, and differences in storage for different ground-water levels.

Table 2.-- Precipitation, water levels, and volume of water withdrawn for selected periods at the Hemphill coal shaft

[in. = inches; ft = feet; Mgal = million gallons; ft^3/s = cubic feet per second]

	September 10-14, 1987	July 2-6, 1988	December 3-9, 1988	April 10-16, 1989
Precipitation for previous 5 days (in.)	0.70	0	0.13	0.75
Precipitation during period (in.)	.54	0	.02	.19
Initial minimum daily water level (ft below land surface)	86.92	40.71	42.37	39.87
Final minimum daily water level (ft below land surface)	86.99	41.13	42.73	40.33
Decline in minimum daily water level (ft below land surface)	.07	.42	.36	.46
Average minimum daily water level (ft below land surface)	86.87	40.89	42.53	40.14
Volume of withdrawal during period (Mgal)	5.0	8.3	7.0	7.4
Volume of water withdrawn, per 1 ft decline in water level (Mgal/ft)	71.4	19.8	19.4	16.1
Mean daily discharge, Tug Fork River near Welch (ft^3/s)	67	63	53	301

During September 10-14, 1987, withdrawal of 5.0 Mgal of water resulted in a 0.07-ft decline in minimum daily water level. At this rate of water-level decline, withdrawal of 71.4 Mgal of water would result in a 1-ft decrease in water level. The average minimum daily water level during this period was 86.87 ft below land surface.

During July 2-6, 1988, withdrawal of 8.3 Mgal of water resulted in a 0.4-ft decline in minimum daily water level. At this rate of water-level decline, withdrawal of about 19.8 Mgal of water would result in a 1-ft decrease in water level. The average minimum daily water level during this period was about 41 ft below land surface.

During December 3-9, 1988 withdrawal of 7.0 Mgal of water resulted in a 0.4-ft decline in minimum daily water level. At this rate of water-level decline, withdrawal of 19.4 Mgal would result in a 1-ft decrease in water level. The average minimum daily water level during this period was 42 ft below land surface.

During April 10-16, 1989, withdrawal of 7.4 Mgal of water resulted in a decline in the minimum daily water level of 0.5 ft. At this rate of water-level decline, a 1-ft decrease in water level would result from withdrawal of 16.1 Mgal of water. The average minimum daily water level during this period was 40 ft below land surface.

The volume of water withdrawn per foot of drawdown during September 10-14, 1987, was much greater than during other periods. This drawdown was before the 50-ft rise in water level described in the "Fluctuations" section of this report. The water level in the coal shaft was about 45 to 50 ft lower than during other periods of analysis. The large volume of water withdrawn per foot of drawdown during this period indicated a larger amount of recharge at this water level than at higher water levels, and possibly greater storage at this level. Recharge from overlying rocks and the Tug Fork probably is greater at this water level than at higher water levels, because of the decreased head in the mine system. A fracture zone that can supply large amounts of water also could be about 80 to 90 ft below land surface at the coal shaft. Antecedent precipitation and precipitation during the period of analysis also could have contributed somewhat to recharge during this time period; however, discharge in the Tug Fork did not increase during this time.

The volume of water withdrawn per foot of water-level decline during the other three periods ranged from about 16 to 20 Mgal per ft of drawdown. These rates of water-level decline probably are representative of conditions after the water-level rise in 1987. Water-level declines during the period from April 10 to 16, 1988, probably was affected by precipitation, as indicated by flow in the Tug Fork. Average daily discharge in the Tug Fork was 301 ft^3/s during April 10 to 16, 1988, compared to 63 ft^3/s during July 2-6, 1988, and 53 ft^3/s during December 3-9, 1988.

Water levels rose about 2 ft at the coal shaft and 1.7 ft at well 2 on September 19, 1989, during a 2-hour and 15-minute period when the Welch Water Department stopped pumping. Nearly 2 in. of rain had fallen during the 40 hours before the pumps were stopped. The recent rain probably was a major factor in the rapid water-level rise.

Pumping of well 7, which is drilled into the Pocahontas No. 3 seam, caused no change in water levels in the coal shaft or in well 2, which is located about 100 ft south of well 7. Water yield of well 7 is insufficient to operate the pump for extended periods. On several occasions, pumping of well 7 at a rate of 600 gal/min for 2 to 5 minutes caused no change in water levels in well 2 or in the coal shaft. Mine maps indicated that well 7 was drilled along the western edge of the Pocahontas No. 3 seam. The drillers reported hitting a solid block of coal (probably a pillar) in the Pocahontas No. 4 seam and a mine opening at the level of the Pocahontas No. 3 seam (Donald Stroupe, Welch Water Department, oral commun., 1989). The well is cased to 610 ft and the lower 80 ft of casing is slotted. Collapse of the mine roof and pressure from the overlying Pocahontas No. 4 coal pillar could have effectively sealed the area tapped by well 7 from the rest of the Pocahontas No. 3 seam.

Storage and Availability of Mine Water

Estimates of the storage capacity of the mines were based on the volume of coal removed. Mines in the Pocahontas No. 4 seam covered an area of about 1.9 mi^2. Removal rates of coal were estimated to be about 80 percent. The average thickness of coal in this seam was about 5 ft. The total void space created by mining in the Pocahontas No. 4 seam could thus contain about 1.6×10^9 gal of water.

Mines in the Pocahontas No. 3 seam covered an area of 2.8 mi^2. As a result of poor mining conditions, removal rates of coal were estimated to be only 50 percent. The average thickness of coal mined in this seam was about 5 ft. The total void space created by mining in the Pocahontas No. 3 seam could thus contain about 1.5×10^9 gal of water.

Although subsidence fracturing and roof falls could have decreased void space in the mines, the corresponding increase in void spaces in the overburden could result in a combined volume nearly equal to the volume of coal that was removed in mining. Some additional storage is present in the voids formed by natural fractures and intergranular spaces in the rock that overlies the mine. The thickness of the rock overlying the Pocahontas No. 4 coal seam ranges from about 250 ft along the Tug Fork, to about 1,000 ft under the hilltops.

The combined void space created by mining in the Pocahontas Nos. 3 and 4 seams could contain about 3.1 $\times 10^9$ gal of water. This volume of water represents more than four times the combined average annual water pumpage for Welch and the communities of Hemphill and Capels. The Exeter Mines are thus estimated to be capable of supplying the water needs of Welch and the communities of Capels and Hemphill during periods of drought.

Quality of Mine Water

The chemical composition of water from the Exeter Mines indicated areal and seasonal variation. Chemical data for water from well 3 and the coal shaft, collected and analyzed by the West Virginia Department of Health from 1975 through 1977, are listed in tables 3 and 4. Water samples were periodically collected at wells 3 and 5 and the Hemphill coal shaft from September 1986 through September 1988 as part of this study. Water samples from wells 3 and 5 were collected at the well head, and water samples from the coal shaft were collected before water entered the aerator. The chemical quality of the water is thus not representative of water delivered to customers. Chemical and physical data for the water samples collected during this study are listed in table 5.

Analysis of water collected from well 3 in 1976, the year in which Welch began to use the Exeter Mines as a water supply, indicates temporal variability for several chemical constituents. Chemical quality of water samples collected from August 1987 through September 1988 appears to have changed simultaneously with the rise in water levels.

The ionic type of water from wells 3 and 5, from September 1986 through September 1988, was sodium bicarbonate. From September 1986 through March 1988, the ionic type of water from the Hemphill coal shaft was sodium sulfate. The ionic type of water from the coal shaft after the rise in water levels was sodium bicarbonate. Sodium concentrations in water from the wells and coal shaft exceeded the 20 mg/L level recommended by the West Virginia Department of Health (West Virginia Department of Health, 1981). From September 1986 through March 1988, sulfate concentrations in water from the coal shaft exceeded the 250 mg/L State drinking-water standard, whereas sulfate concentrations in water from wells 3 and 5 were less than 250 mg/L. After the water-level rise, the sulfate concentration in water from the coal shaft was less than 250 mg/L. Iron concentrations in water samples collected during the study from well 5 and the coal shaft typically exceeded the 300 μg/L State drinking-water standard (West Virginia State Board of Health, 1981). Concentrations of manganese in water from wells 3 and 5 and the coal shaft exceeded the 50- μg/L State drinking-water standard in all samples collected during the study. The sources and significance of selected chemical constituents and physical properties of water are listed in table 6.

Table 3.--Chemical analysis of water from well 3, April through August 1976 (Data from West Virginia Department of Health)

[mg/L = milligrams per liter; μg/L = micrograms per liter]

Date	pH stand-ard	Hardness total (mg/L) as $CaCO_3$)	Sodium, total (mg/L as Na)	Alkalinity water wh total LAB (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, total (mg/L as Cl)	Fluoride, total (mg/L as F)	Solids, residue at 180° C dis-solved (mg/L)	Iron, total (μg/L as Fe)	Man-ganese, total (μg/L as Mn)
April 6, 1967	7.7	152	350	736	--	94	0.5	1,390	330	10
May 8, 1976	7.2	124	364	1,077	122	148	.6	2,350	399	20
June 1, 1976	7.4	122	406	663	91	23	.7	2,610	147	16
August 9, 1976	7.4	120	474	1,398	85	278	.4	3,040	1,660	110

Table 4.--Chemical analysis of water from the Hemphill coal shaft, March 19, 1975, and November 8, 1977 (data from West Virginia Department of Health)

[mg/L = milligrams per liter; μg/L = micrograms per liter]

Date	pH	Hardness, total, as $CaCO_3$ (mg/L)	Calcium, total (mg/L as Ca)	Magnesium, total (mg/L as Mg)	Sodium, total (mg/L as Na)	Potassium, total (mg/L as K)	Alkalinity, (mg/L as $CaCO_3$)
March 19, 1975	7.6	110	15	9	128	2.6	236
November 9, 1977	7.2	256	50	5	74	5.0	178

Date	Sulfate, total (mg/L as SO_4)	Chloride, total (mg/L as Cl)	Fluoride, total (mg/L as F)	Solids, residue at 180° C dis-solved (mg/L)	Nitrogen, dissolved NO_2+NO_3 (mg/L as N)	Iron, total recoverable (μg/L as Fe)	Manganese, total recoverable (μg/L as Mn)
March 19, 1975	70	11	0.50	609	0.37	2,600	390
November 8, 1977	200	13	.50	740	.04	4,500	750

Table 5a.--Chemical analysis of water from the Exeter Mines, Well 3

[μS/cm = microsiemens per centimeter at 25 degrees Celsius (°C); mm of Hg = millimeters of mercury; mg/L = milligrams per liter; μg/L = micrograms per liter; -- = data not collected]

Date	Specific conductance (μS/cm)	pH	Water temperature (°C)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as) Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
Sept. 4, 1986	595	6.9	15.0	718	2.5	120	31	11	85	1.5
Aug. 7, 1987	549	7.1	14.5	718	3.2	130	33	11	75	1.5
Sept. 7, 1987	570	7.0	14.0	716	3.5	120	31	11	80	1.4
Mar. 4, 1988	625	7.3	13.5	711	2.0	140	36	12	83	1.4
June 23, 1988	870	8.1	15.0	717	6.8	110	20	14	160	1.9
Sept. 8, 1988	1,150	7.8	16.0	--	2.8	59	13	6.2	250	--

Date	Bicarbonate, water, whole, total, field, (mg/L as HCO_3)	Carbonate, water, whole, total, field, (mg/L as CO_3)	Alkalinity, water, whole, total, field, (mg/L as $CaCo_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2	Solids, residue at 180° C, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)
Sept. 4, 1986	354	0	290	58	13	0.3	11	424	--	<0.10
Aug. 7, 1987	180	0	220	54	9	.2	11	318	--	.26
Sept. 7, 1987	287	0	235	45	11	.2	11	329	--	<.10
Mar. 4, 1988	282	0	231	58	10	.2	12	359	<0.01	<.10
June 23, 1988	410	0	335	82	25	.5	2.7	524	.01	.13

Table 5b.--Chemical analysis of water from the Exeter Mines, Well 5

[μS/cm = microsiemens per centimeter at 25 degrees Celsius (°C); mm of Hg = millimeters of mercury; mg/L = milligrams per liter; μg/L = micrograms per liter; -- = data not collected]

Date	Specific conductance (μS/cm)	pH	Water temperature (°C)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as CaCo3)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
Sept. 4, 1986	1,050	7.7	15.5	720	0.9	73	16	7.8	210	1.9
Aug. 7, 1987	1,130	7.6	16.0	722	2.0	73	16	7.9	230	2.0
Sept. 7, 1987	1,140	7.6	15.5	719	2.7	78	17	8.5	240	2.0
Jan. 22, 1988	1,190	7.6	15.5	718	--	--	--	--	--	2.5
Mar. 4, 1988	1,070	7.7	15.5	717	2.7	87	19	9.4	260	2.0
June 23, 1988	1,190	7.6	16.5	720	2.1	75	17	7.8	250	1.9
Sept. 8, 1988	1,210	7.7	15.5	--	1.8	64	14	6.8	260	1.8

Date	Bicarbonate, water, whole, total, field, (mg/L as HCO_3)	Carbonate, water, whole, total, field, (mg/L as CO_3)	Alkalinity, water, whole, total, field, (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180° C, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)
Sept. 4, 1986	604	0	497	53	32	0.6	7.8	730	--	<0.1
Aug. 7, 1987	630	0	520	42	32	.5	8.5	656	--	<.1
Sept. 7, 1987	622	0	510	51	31	.5	8.8	668	--	.2
Jan. 22, 1988	604	0	495	55	31	.5	8.7	703		

Table 5c.--Chemical analysis of water from the Exeter Mines, Hemphill Coal Shaft

[μS/cm = microsiemens per centimeter at 25 degrees Celsius (°C); mm of Hg = millimeters of mercury; mg/L = milligrams per liter; μg/L = micrograms per liter; -- = data not collected]

Date	Specific conductance (μS/cm)	pH	Water temperature (°C)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
Sept. 4, 1986	990	7.0	15.5	723	2.2	290	60	33	110	8.2
Aug. 7, 1987	1,000	7.1	16.0	723	2.1	290	61	33	98	6.7
Sept. 7, 1987	1,130	7.0	15.9	721	1.1	330	69	38	120	7.3
Jan. 22, 1988	1,140	7.0	15.0	721	.6	300	63	34	130	6.9
Mar. 4, 1988	900	7.1	14.0	721	4.1	260	56	28	120	5.0
June 23, 1988	1,030	7.6	15.0	722	<1.0	140	33	13	190	2.8
Sept. 8, 1988	1,100	7.4	14.5	--	.1	120	30	11	210	--

Date	Bicarbonate, water, whole, total, field, (mg/L as HCO_3)	Carbonate, water, whole, total, field, (mg/L as CO_3)	Alkalinity, water, whole, total, field, (mg/L as $CaCo_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180° C, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)
Sept. 4, 1986	283	0	232	290	13	0.2	10	684	--	<0.1
Aug. 7, 1987	262	0	215	280	13	.2	11	622	--	<.1
Sept. 7, 1987	280	0	230	350	14	.2	11	729	--	<.1
Jan. 22, 1988	287	0	235	330	17	.3	8.7	734	--	<.1
Mar. 4, 1988	274	0	225	270	17	.2	8.8	634		

Table 6.--Source and significance of dissolved constituents and physical properties of ambient water (Modified from Mull and others, 1981, table 12, p. 39)

Constituent or physical property	Source or cause	Significance
Bicarbonate (HCO_3) and carbonate (CO_3)	Derives from action of carbon dioxide in water on rocks containing carbonate material such as limestone.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium decompose in hot water facilities to form scale and release corrosive carbon dioxide. Causes carbonate hardness in combination with calcium and magnesium.
Calcium (Ca) and magnesium (Mg)	Dissolves from practically all rocks but particularly limestone and gypsum. Calcium and magnesium are found in some brines.	Causes most of the hardness and scale-forming properties of water; consumes soap (see "Hardness"). Water low in calcium is desired for electroplating, tanning, dyeing, and textile manufacturing.
Chloride (Cl)	Dissolves from rocks and soils. Present in sewage and brines.	Gives a salty taste to water when combined with sodium. In large quantities it increases corrosiveness of water. The secondary drinking-water standard for chloride is 250 mg/L because of taste problems encountered at concentrations above this level (West Virginia State Board of Health, 1981).
Fluoride (F)	Dissolves in small quantities from most rocks and soils.	Fluoride in drinking water reduces incidence of tooth decay when water is consumed during the period of enamel calcification. At high concentrations, it can cause mottling of teeth.
Iron (Fe)	Dissolves from practically all rocks and soils. Can also derive from iron pipes, pumps, and other equipment.	Iron in ground water oxidizes to reddish-brown sediment when exposed to air. Concentrations greater than or equal to 300 μg/L can stain laundry and plumbing fixtures, cause an unpleasant taste, and promote growth of iron bacteria. Secondary drinking-water standard is 300 μg/L (West Virginia State Board of Health, 1981).
Manganese (Mn)	Dissolves from some rocks and soils. Not as common as iron.	Same objectionable features as iron. Causes dark brown or black stain. State-recommended secondary drinking-water standard is 50 μg/L (West Virginia State Board of Health, 1981).
Silica (SiO_2)	Dissolves from most rocks and soils, usually in small amounts of 1 to 50 mg/L.	Forms hard scale in pipes and boilers.
Sodium (Na) and potassium (K)	Dissolves from most rocks and soils. Found in brines, sea water, some industrial waste water, and sewage.	In large amounts, in combination with chloride, gives water a salty taste. Moderate quantities have little effect on usefulness of water for most purposes. Large concentrations of sodium could be of concern to individuals on sodium-restricted diets.

Table 6.--Source and significance of dissolved constituents and physical properties of ambient water --Continued

Constituent or physical property	Source or cause	Significance
Sulfate (SO_4)	Dissolves from rocks and soils containing gypsum, iron sulfide, and other sulfur compounds. Usually present in mine water and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate, when combined with other ions, gives a bitter taste to water and can have a laxative effect. A secondary drinking-water standard of 250 mg/L has been set by the West Virginia State Board of Health (West Virginia State Board of Health, 1981).
Dissolved solids	Chiefly mineral constituents, dissolves from rocks and soils. Can include organic matter.	Water containing dissolved solids in excess of 1,000 mg/L is unsuitable for many industrial purposes. Secondary drinking-water standard is 500 mg/L (West Virginia State Board of Health, 1981).
Hardness, as $CaCO_3$	Hardness in most water is primarily due to calcium and magnesium.	Consumes soap before a lather will form. Deposits soap curd on laundry fixtures. Scale will form in boilers, water heaters, and pipes containing hard water. Water with hardness concentrations of 60 mg/L or less is considered soft; water with concentrations from 61 to 120 mg/L is considered moderately hard; water with concentrations from 121 to 180 mg/L is considered hard, and water with concentrations of more than 180 mg/L is considered very hard.
pH	Acids, acid-generating salts, and carbon dioxide lower pH. Carbonates, bicarbonates, hydroxides, phosphates, and silicates raise pH.	A pH of 7.0 indicates neutrality. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity from neutrality. pH is a measure of the log of the activity of hydrogen ions. Corrosiveness of water generally increases with decreasing pH; however, excessively alkaline water can also be corrosive to metals. The secondary drinking-water standard for pH is between 6.5 and 8.5 (West Virginia State Board of Health, 1981).
Specific conductance (microsiemens per centimeter at 25° C)	Mineral content of water.	Specific conductance is a measure of the capacity of water to conduct an electrical current. Varies with concentration and degree of ionization of the dissolved constituents.

Factors Affecting Water Quality

Factors that affect the chemical quality of ground water include the mineralogy of the rocks through which the water flows, the length of residence time, and the sources and chemical composition of recharge. Residence time is defined as the length of time water has been in the ground-water system--shallow ground water generally has had a shorter residence time than deep ground water. As water moves through rocks, its chemical properties change. Generally, water becomes more mineralized as residence time increases. Some constituents, however, such as iron and manganese, can react with dissolved oxygen in water and precipitate as hydroxides, resulting in concentrations of iron and manganese that decline as residence time increases. As water flows along or seeps through clay layers, sodium-calcium ion exchange is possible. This involves an exchange of calcium ions in water for sodium ions in clay. The result of sodium-calcium ion exchange is a decrease in calcium content and an increase in the sodium content of the water.

Analyses of ground water from wells that tap rocks of the Pottsville Group in the Tug Fork basin indicate that some physical characteristics and concentrations of some chemical constituents vary with depth (table 7) (Bader, 1984; Bader and others, 1989). Water from deep sources generally has had a longer residence time than water from shallow sources. Variation in chemical characteristics of water from wells of different depths can thus be similar to the variation expected for different residence times. Median values of specific conductance, pH, alkalinity, and concentrations of sodium and dissolved solids in water are larger for deep wells (depths greater than 150 ft) than for shallow wells (depths less than 50 ft). Median values of specific conductance and dissolved-solids concentrations also are larger in deep wells than in shallow wells. This indicates an increased mineral content with depth, and, consequently, length of residence time. Large concentrations of sodium in water from deep wells probably is the result of ion exchange. Median values of iron and manganese concentrations are less in water from deep wells than in water from shallow wells. The differences in concentrations of iron and manganese with depth primarily are because of the precipitation of iron and manganese as residence time increases.

Analyses of samples obtained during the study indicate that the quality of water in the Exeter Mines is affected by the source of recharge and the length of residence time. Under ambient conditions (no pumping), the water with the longest residence time probably is in the deepest part of the mines, along the northwest boundary. Withdrawal of water from the mines altered natural circulation patterns, however, and caused an overall decrease in the residence time of water in the mines. Overburden thickness is greater in the vicinity of wells 3 and 5 than in the vicinity of the Hemphill shaft. The water that enters the mines from the overburden thus probably has a longer residence time near wells 3 and 5 than the water that enters the mines near the coal shaft, which is in the Tug Fork valley where overburden is less thick.

The Tug Fork is a source of recharge for the Exeter Mines, particularly for the coal shaft because of its proximity to the river. Comparison of the ionic composition of water from wells 3 and 5, the coal shaft, and the Tug Fork (at low flow) indicates that the ionic composition of water from the coal shaft is more similar to the ionic composition of water from the Tug Fork than to the ionic composition of water from wells 3 and 5 (fig. 17). The ionic composition of water from well 3 is the least similar to the ionic composition of water from the Tug Fork. Well 5 is nearer the river than is well 3, and pumping from wells 5 and 6 induces flow from the river. Well 3 is not pumped routinely; hence, the source of water withdrawn from well 3 probably is the overburden and rocks surrounding the mines.

Variation of specific conductance with depth was measured for the upper 270 ft of water in the Hemphill air shaft in September 1989 (fig. 18). Measurements were limited to the upper 270 ft of water in the shaft because of the length of the conductance-probe cable. Specific conductance at the surface of the water was about 1,150 μS/cm. Specific conductance increased with depth to 1,770 μS/cm about 80 ft below water surface. At about 90 ft below water surface, specific conductance was about 550 μS/cm. From 90 to 190 ft below water surface, specific conductance of the water increased from about 550 to 990 μS/cm. At 200 ft below water surface, specific conductance increased to 2,400 μS/cm. Conductance increased with depth from 2,400 to 2,590 μS/cm at 270 ft below water surface, the maximum depth measured. The altitude of the top of the air shaft is about 8 ft below that of the coal shaft.

The variation in conductance with depth probably was caused by differences in residence time and circulation paths of water in the vicinity of the air shaft. The specific conductance probably increases proportionally to length of residence time of the water. Water with small specific conductance probably has had less residence time than water with large specific conductance. Withdrawal of water from the coal shaft and wells 5 and 6 appears to induce flow of water from the Tug Fork into the mines. Water probably flows primarily at

Table 7.-- Summary of concentrations of selected constituents and physical characteristics of ground water from the Pottsville Group by well depth[1]
[ft = feet; μs/cm = microsiemens per centimeter at 25 degrees Celsius; mg/L = milligrams per liter; μg/L = micrograms per liter]

Constituent	Well depth, in feet below land surface								
	Less than 50			50 to 150			Greater than 150		
	Range	Median	Number of wells	Range	Median	Number of wells	Range	Median	Number of wells
Specific conductance (μs/cm at 25 ° C)	50-840	290	48	66-1,980	280	103	200-900	400	15
pH	5.6-9.0	6.8	48	5.7-8.3	6.8	103	6.5-8.2	7.5	15
Hardness (mg/L as $CaCO_3$)	12-440	93	48	1-420	110	100	100-320	140	15
Sodium, dissolved (mg/L as Na)	1.4-190	--	48	2.3-400	24	100	7.4-170	38	15
Alkalinity (mg/L as $CaCO_3$)	.6-160	10	48	.8-470	8.2	100	1.4-59	9.2	15
Sulfate, dissolved (mg/L as SO_4)	.4-150	18	48	0-610	12	100	.4-190	29	15
Chloride, dissolved (mg/L as Cl)	20-220	78	48	17-580	76	100	42-520	130	15
Dissolved solids (residue at 180°C) (μg/L)	56-545	173	48	48-3,220	176	100	147-738	267	15
Iron, dissolved (μg/L as Fe)	10-39,000	1,800	48	10-67,000	1,100	99	10-2,400	80	15
Manganese, dissolved (μg/L as Mn)	30-4,800	200	48	1-4,700	140	99	2-420	30	15

[1] Modified from Bader, 1984.

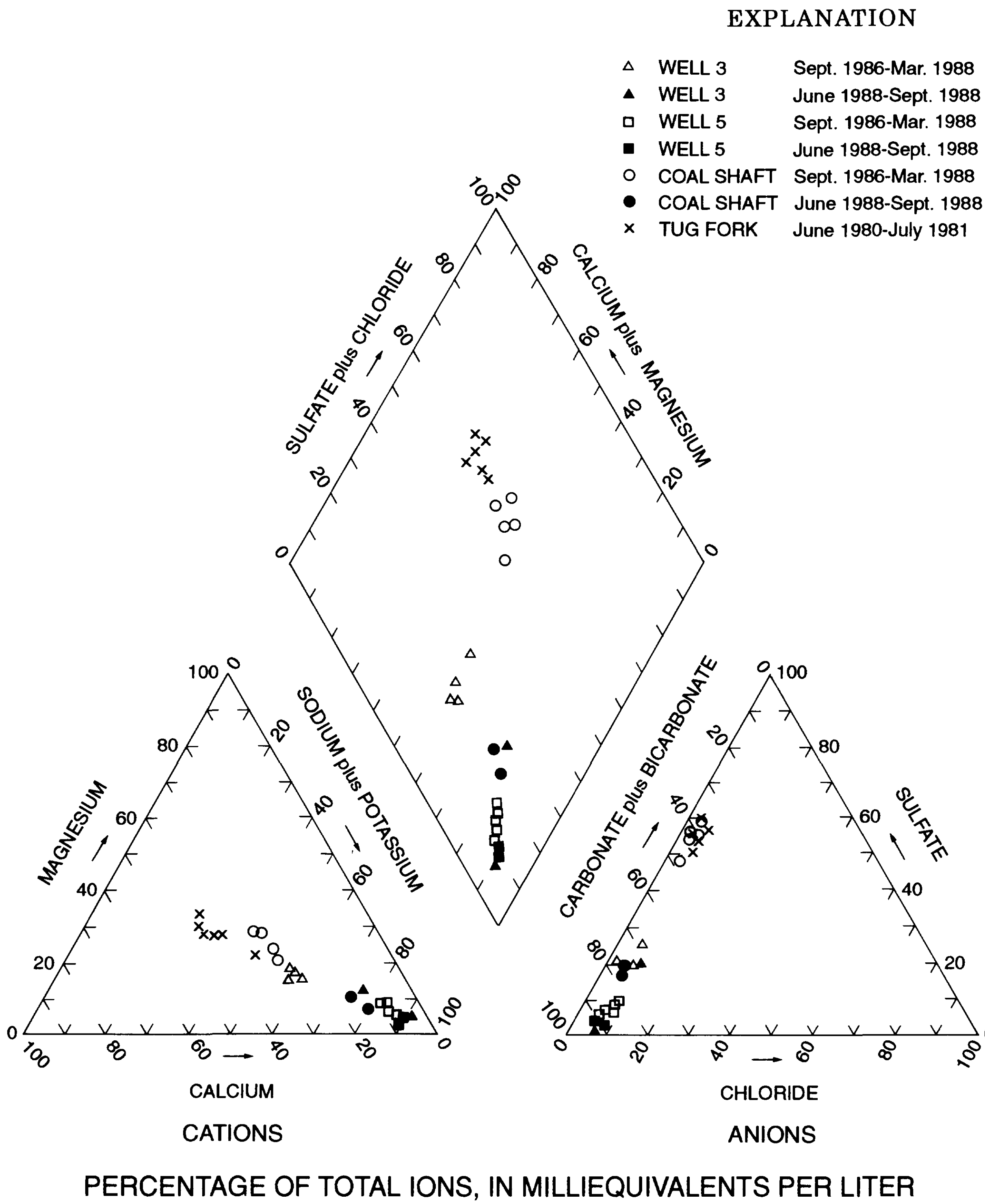

Figure 17.--Ionic composition of water samples from the Exeter Mines and the Tug Fork.

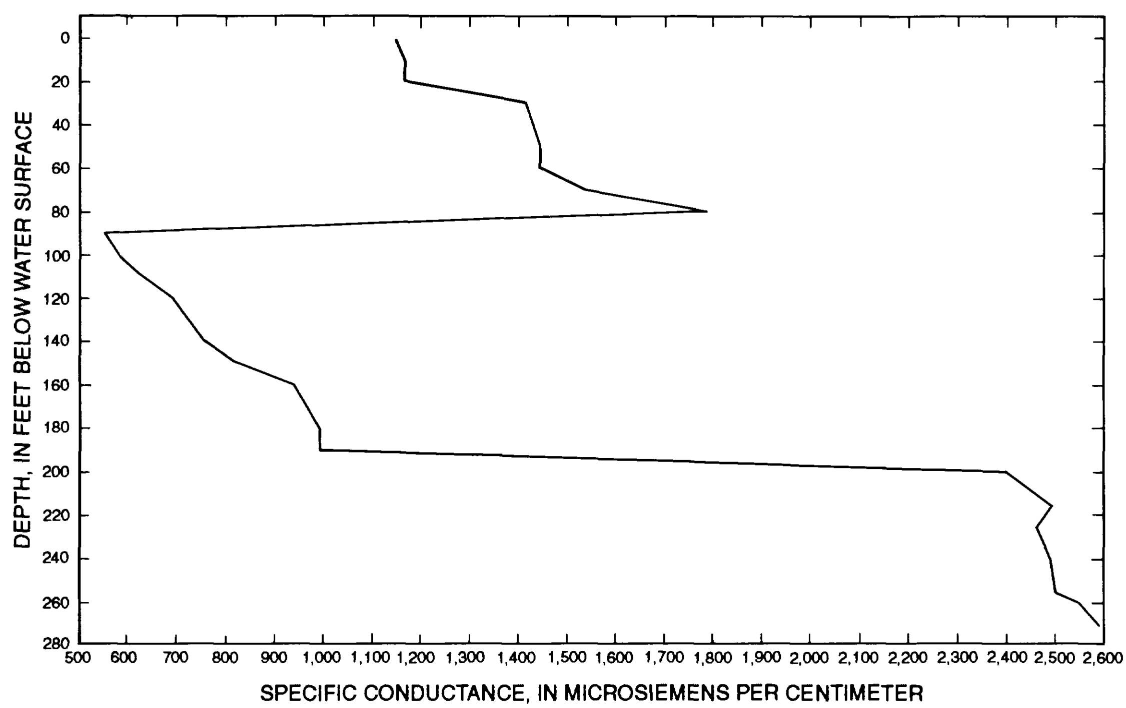

Figure 18.--Variation in specific conductance with depth in water from the Hemphill air shaft.

depths from about 90 to 190 ft below the surface of water in the air shaft, which is approximately equal to an altitude of 1,200 to 1,100 ft above sea level. This zone, from about 90 to 190 ft below land surface, probably contains numerous interconnected fractures and bedding-plane separations. The fractures in this zone could be connected to vertical fractures in the bed of the Tug Fork that permit downward movement of water from the river into the fracture zone and through the fracture zone into the mines. Another explanation is that the fracture zone could connect the Exeter Mines to the adjacent mines, thus permitting flow of water between the Exeter Mines and the adjacent mines. The presence of a water-bearing fracture zone at this altitude range could correspond to the decreased rate of water-level decline per volume of withdrawal at a minimum daily water level of 87 ft, which was observed in the hydrograph analysis for September 10 to 14, 1987. The large amount of water that inflows through this fracture zone probably prevents large drawdowns at water levels that are less than 90 ft below land surface at the coal shaft. The large specific conductance of water at depths greater than 190 ft (1,200 ft above sea level) indicates that water circulates little below this level. The altitude of the pump in the coal shaft is 1,165 ft above sea level.

Changes in Chemical Quality Caused by Development of Mine as a Water Supply

Concentrations of several chemical constituents of mine water changed during this study (figs. 19-26). The most pronounced changes were increases in concentrations of sodium and chloride, and increases in hardness and alkalinity. Calcium and sulfate concentrations decreased. The largest changes in water quality with respect to the rise in water levels were in water from the coal shaft. Concentrations of magnesium in water from the coal shaft decreased from a range of 33 to 43 mg/L from September 1986 through March 1988, to a range of 11 to 12 mg/L after the rise in water levels (fig. 23). Concentrations of dissolved solids increased in water from well 3, from a range of 318 to 424 mg/L, to a range of 525 to 686 mg/L after the rise in water levels (fig. 24). The concentration of iron in water from the coal shaft decreased from a range of 2,400 to 3,700 μg/L before water levels rose, to a range of 220 to 360 μg/L after water levels rose (fig. 25). Similarly, concentrations of manganese in water from the coal shaft decreased from a range of 790 to 970 μg/L, to a range of 260 to 320 μg/L after water levels rose (fig. 26). Concentrations of iron and manganese in water collected from well 3 on March 4, 1988, were much larger than concentrations in water collected from well 3 at other times. The March 4, 1988, water sample was collected after a period of heavy rain. It is probable that infiltration of precipitation had replenished shallow ground-water supplies, and inflow of shallow ground water through the uncased well bore constituted a significant amount of recharge to well 3 at this time.

Most of the changes in water quality that were observed during the study probably were associated with the rise in water levels. Because of the large increase in storage of water that resulted from the rise in water levels, the average residence time of water in the mines also increased. Increased water levels in the mines reduced the rate of inflow of water from the Tug Fork. Changes in water quality that were observed during the study probably are largely the result of increased residence time and decreased inflow from the Tug Fork.

Chemical quality of water from wells 3 and 5 and the coal shaft changed when the Welch Water Department began to withdraw water from the Exeter Mines (Donald Stroupe, Welch Water Department, oral commun., 1988). Welch Water Department operators reported that, on several occasions, shortly after withdrawals from the Exeter Mines began, water pumped from the mines contained large amounts of fine-size coal particles. The operators attributed the presence of fine-size coal particles to roof falls in the mines (Donald Stroupe, Welch Water Department, oral commun., 1988).

Analyses of water from well 3, performed by the West Virginia Department of Health, indicate some variability in water quality during the first few months of pumping (table 3, figs. 27-29). Alkalinity values and concentrations of sodium, chloride, dissolved solids, iron, and manganese in water from well 3 generally increased during the initial months of pumping. Most of the changes in water quality during the first months of pumping probably were the result of gradual replacement of water that had been in the mines for a long time by water of more recent origin.

The quality of water from the coal shaft changed after Welch began to use the mines for water supply (table 4). Prior to pumpage by the city of Welch, the ionic type of water in the coal shaft was sodium bicarbonate. About one year after Welch began using the Exeter Mines to supply water, the ionic type of water in the coal shaft had changed to sodium sulfate. Water hardness values, and calcium, sulfate, iron, and manganese concentrations increased with the additional pumpage from the mines by Welch. Alkalinity, pH, and the concentration of sodium decreased. These changes correspond to decreased residence times and increased inflow from the Tug Fork, which resulted from the increase in withdrawals. The changes in the quality of water from the coal shaft from 1975 through 1977 indicate the effects of decreased residence time and increased inflow from the Tug Fork. These changes in water quality contradict those during the study because of increased residence time and decreased inflow from the Tug Fork, which resulted from flooding of adjacent mines.

Using coal mines for water supply presents some problems not typically encountered with other ground-water sources used for water supply. Water quality could change as a result of changes in pumpage and residence time. Changes in activity in nearby mines can have a major effect on water quality within the mines, because of changes in residence time.

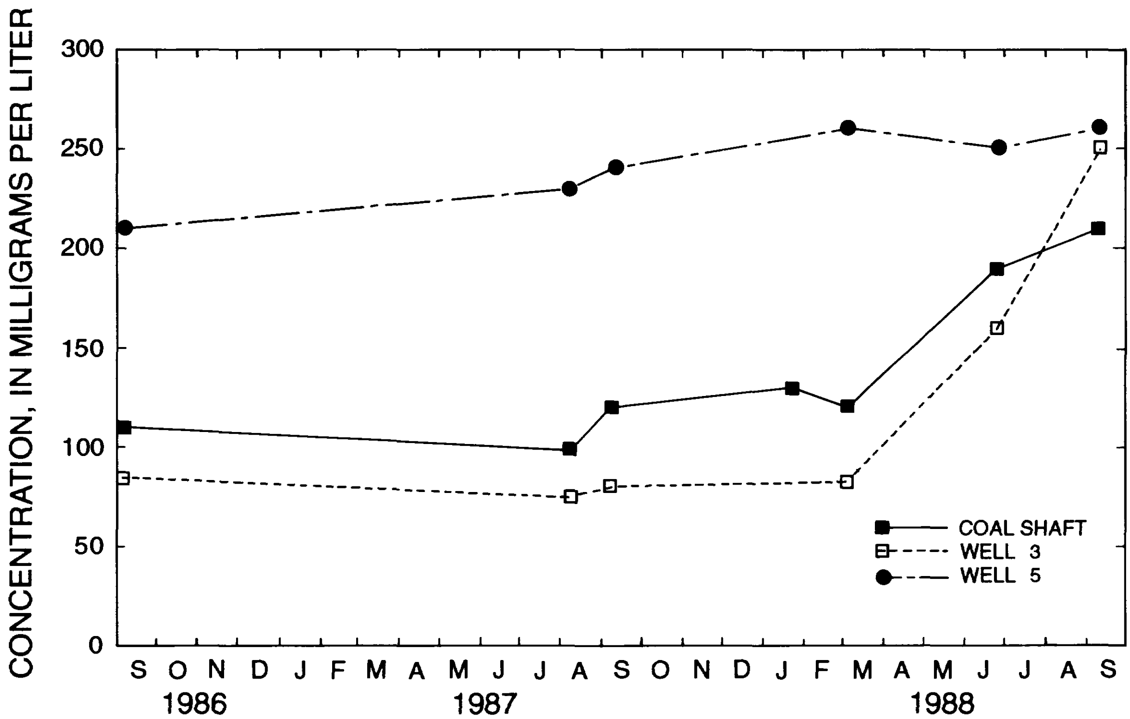

Figure 19.--Concentration of dissolved sodium in water from the Exeter Mines.

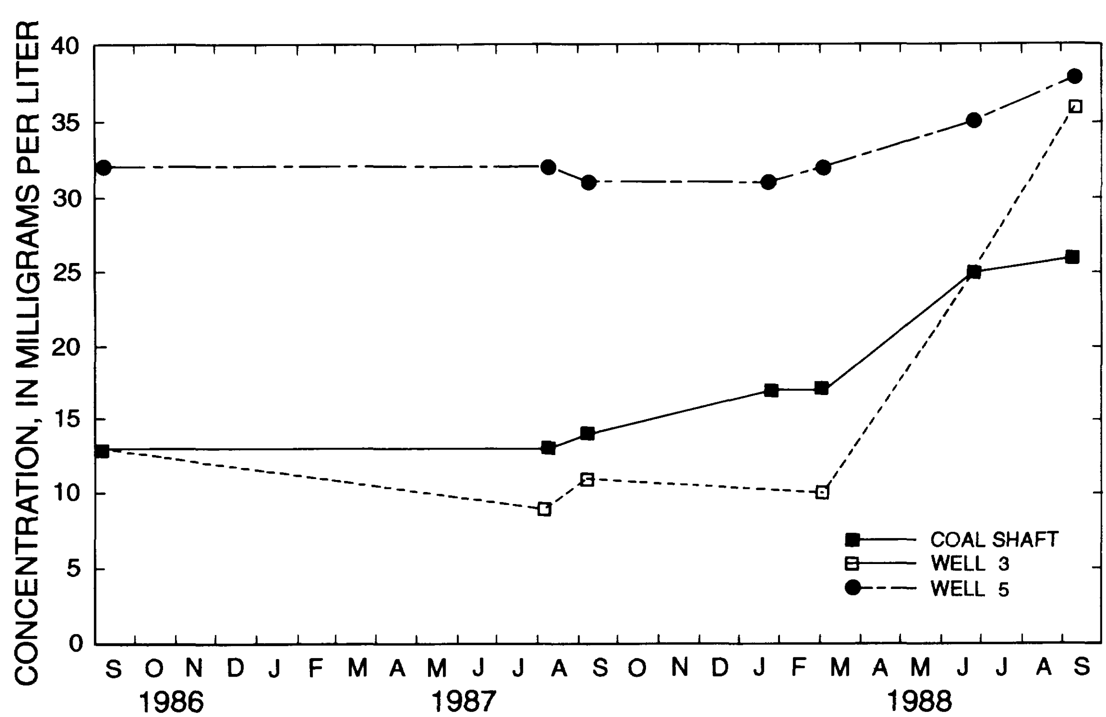

Figure 20.--Concentration of dissolved chloride in water from the Exeter Mines.

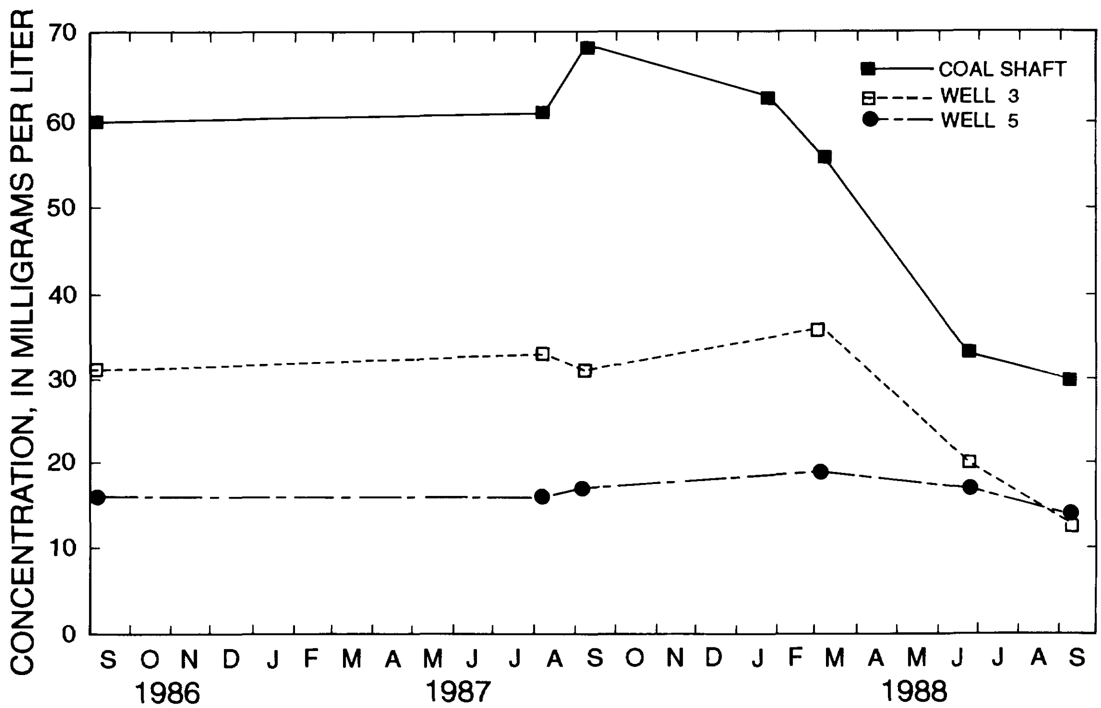

Figure 21.--Concentration of dissolved calcium in water from the Exeter Mines.

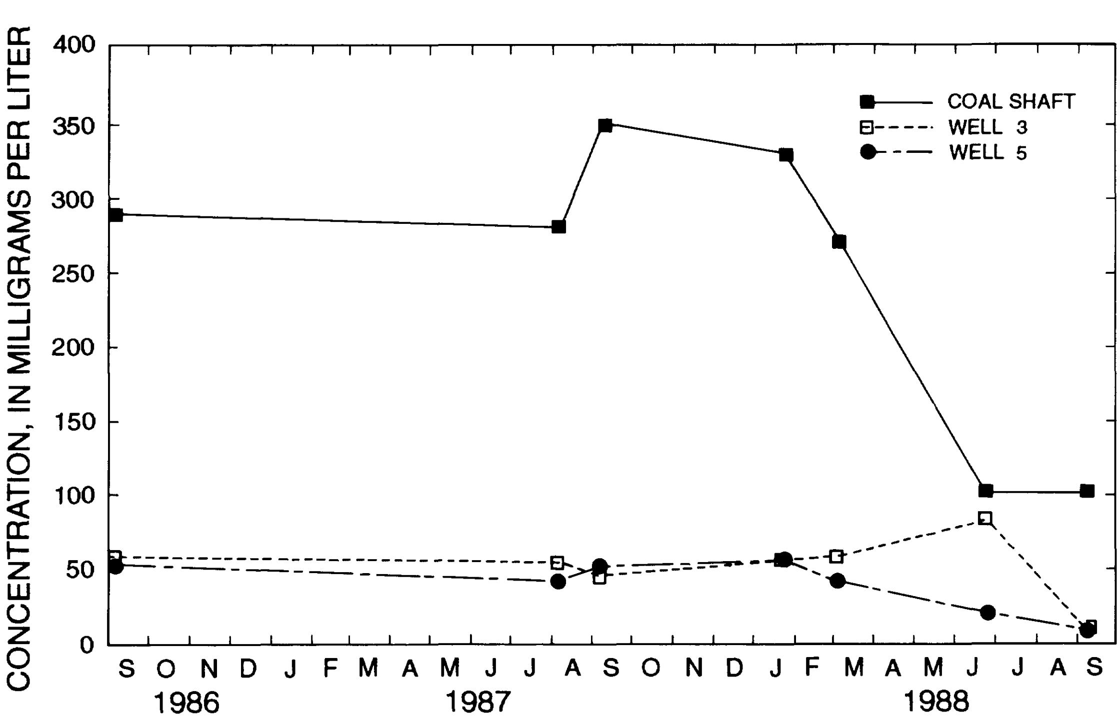

Figure 22.--Concentration of dissolved sulfate in water from the Exeter Mines.

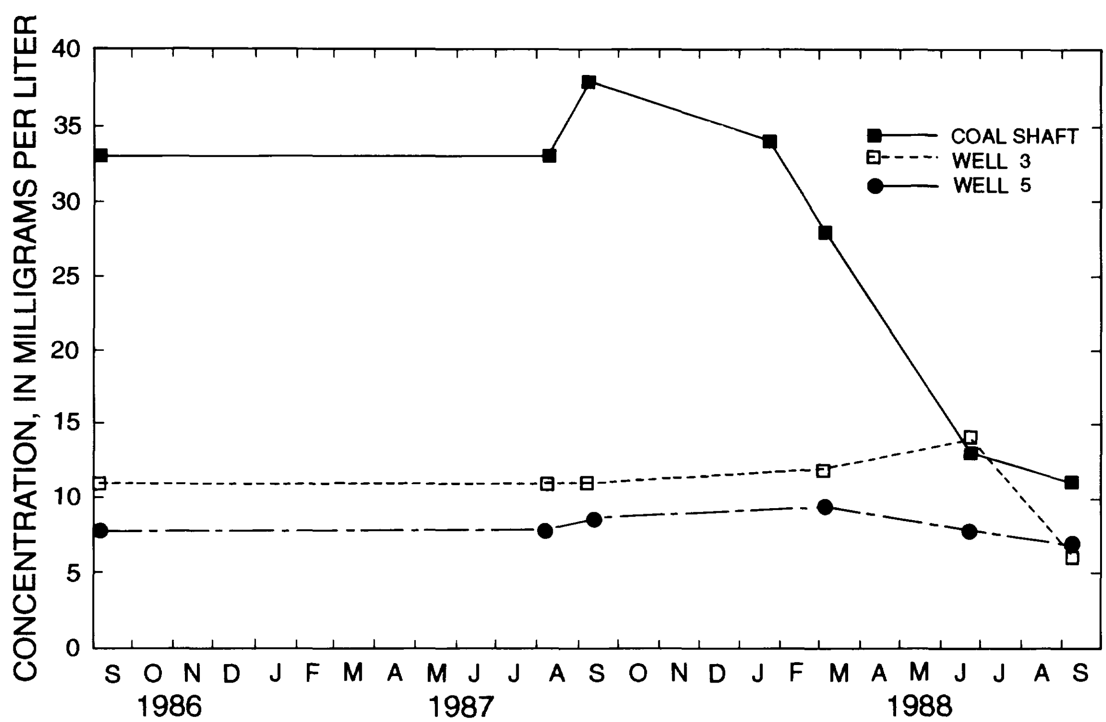

Figure 23.--Concentration of dissolved magnesium in water from the Exeter Mines.

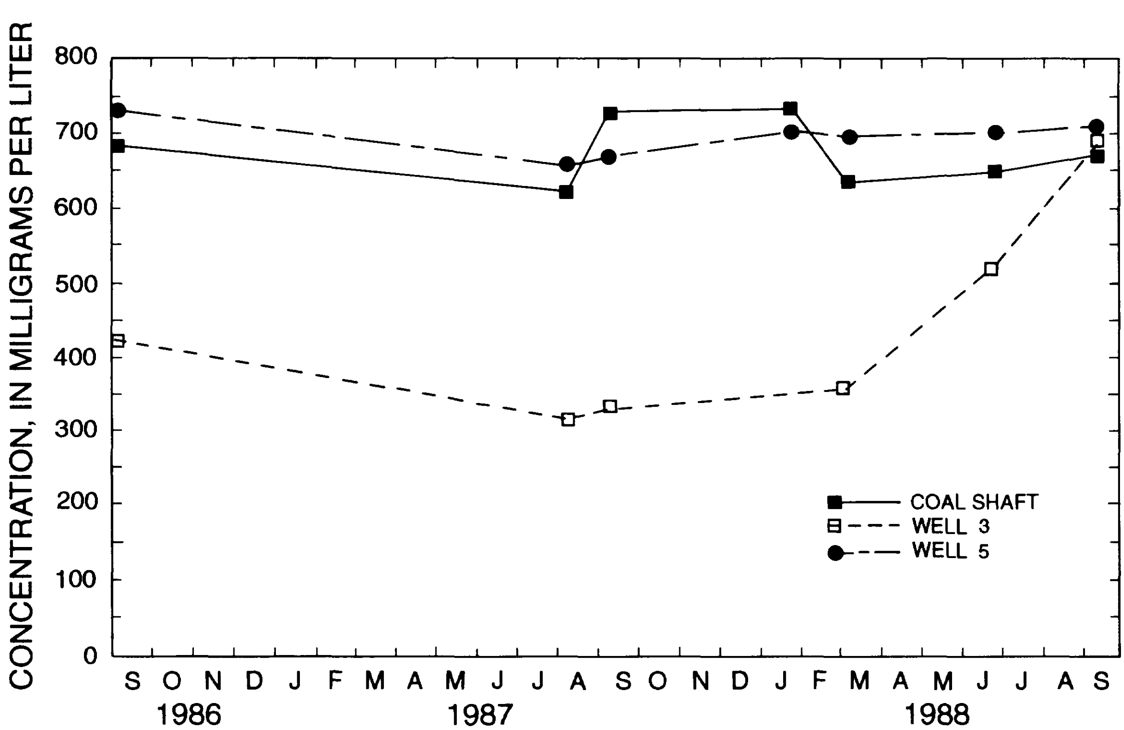

Figure 24.--Concentration of dissolved solids in water from the Exeter Mines.

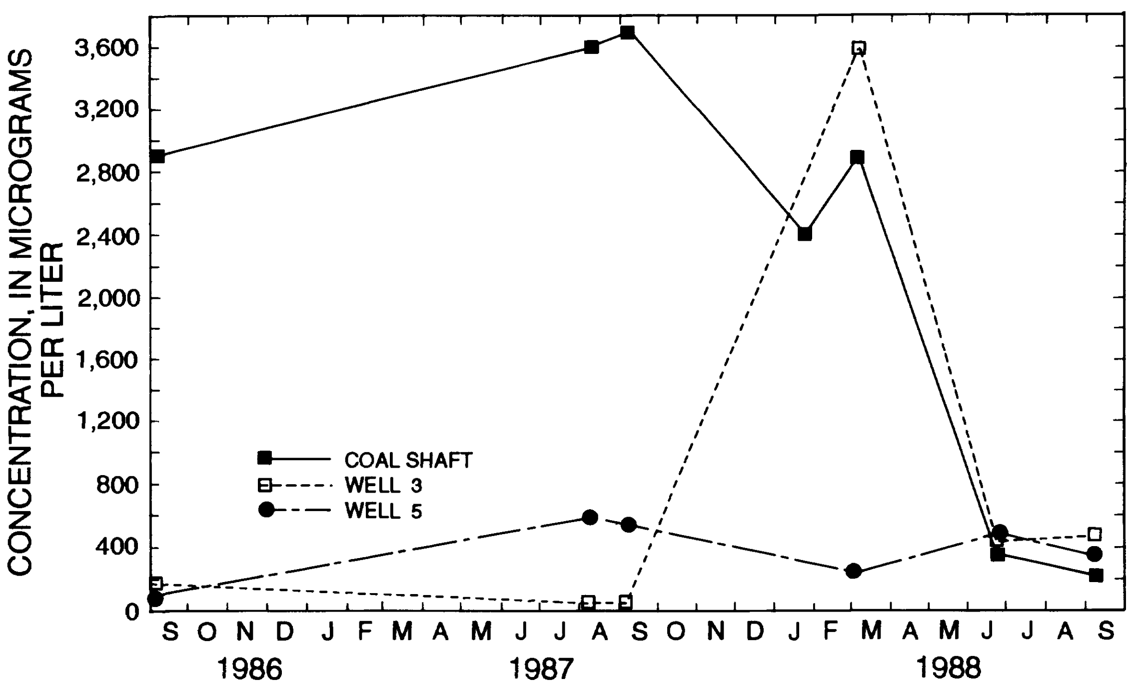

Figure 25.--Concentration of dissolved iron in water from the Exeter Mines.

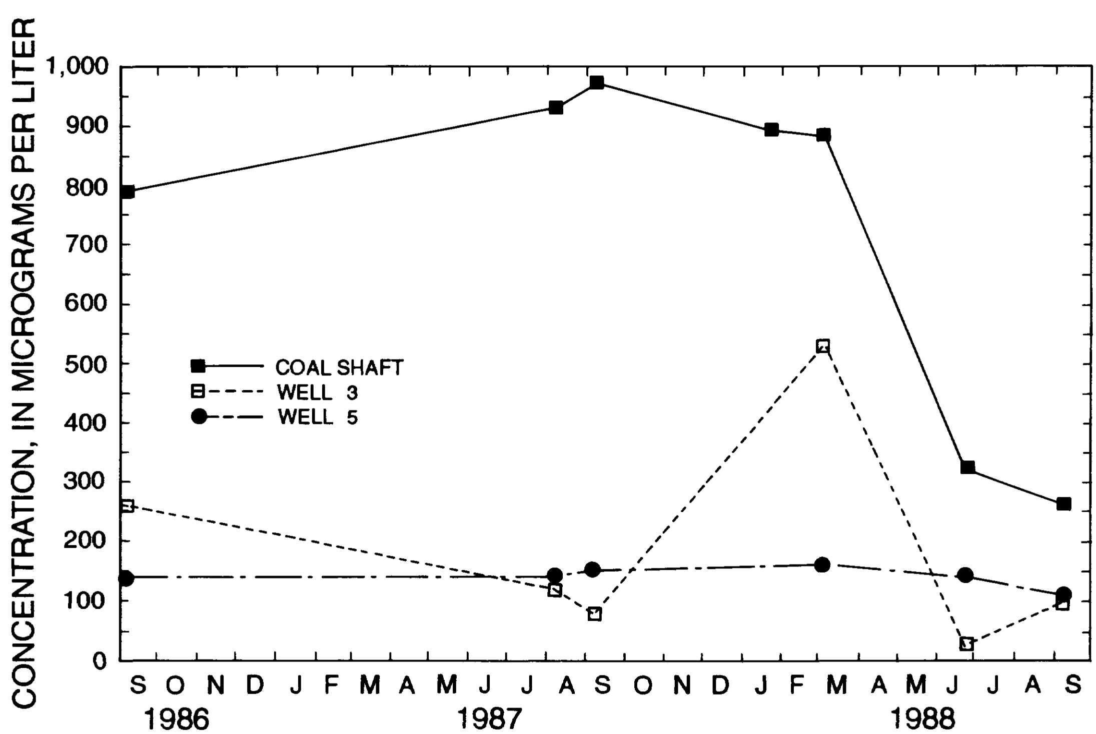

Figure 26.--Concentration of dissolved manganese in water from the Exeter Mines.

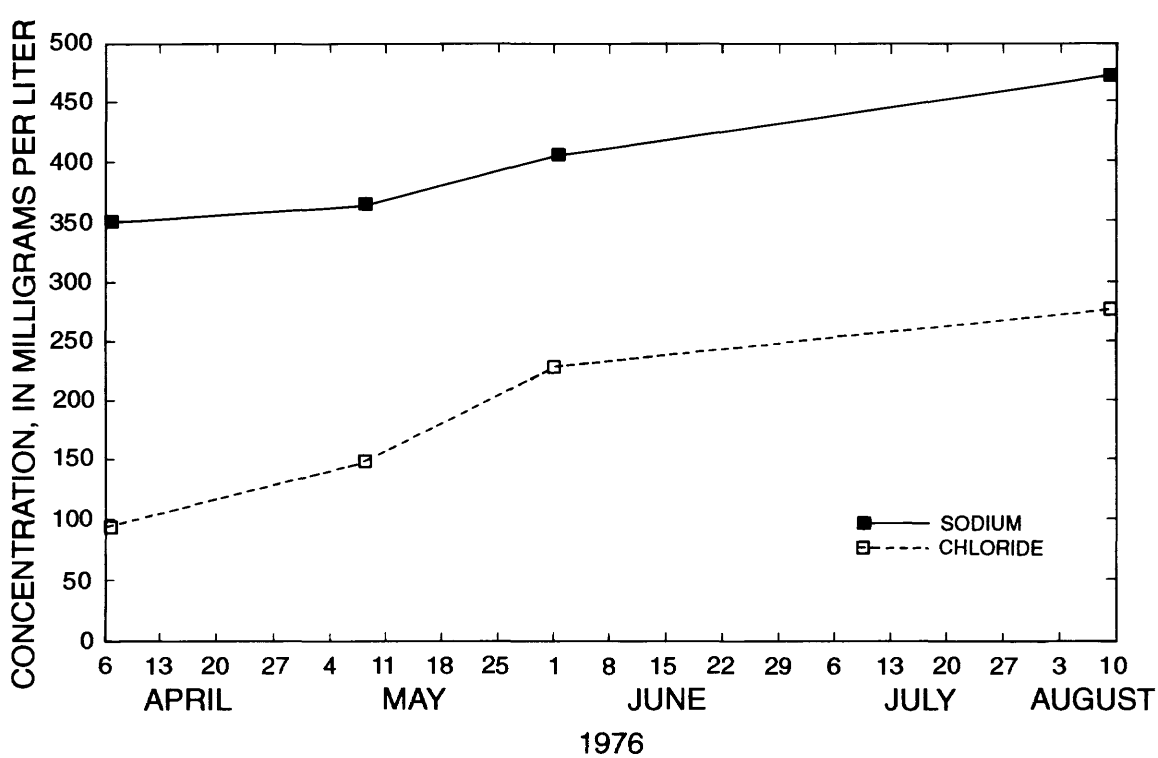

Figure 27.--Concentrations of sodium and chloride in water from well 3, April through August 1976.

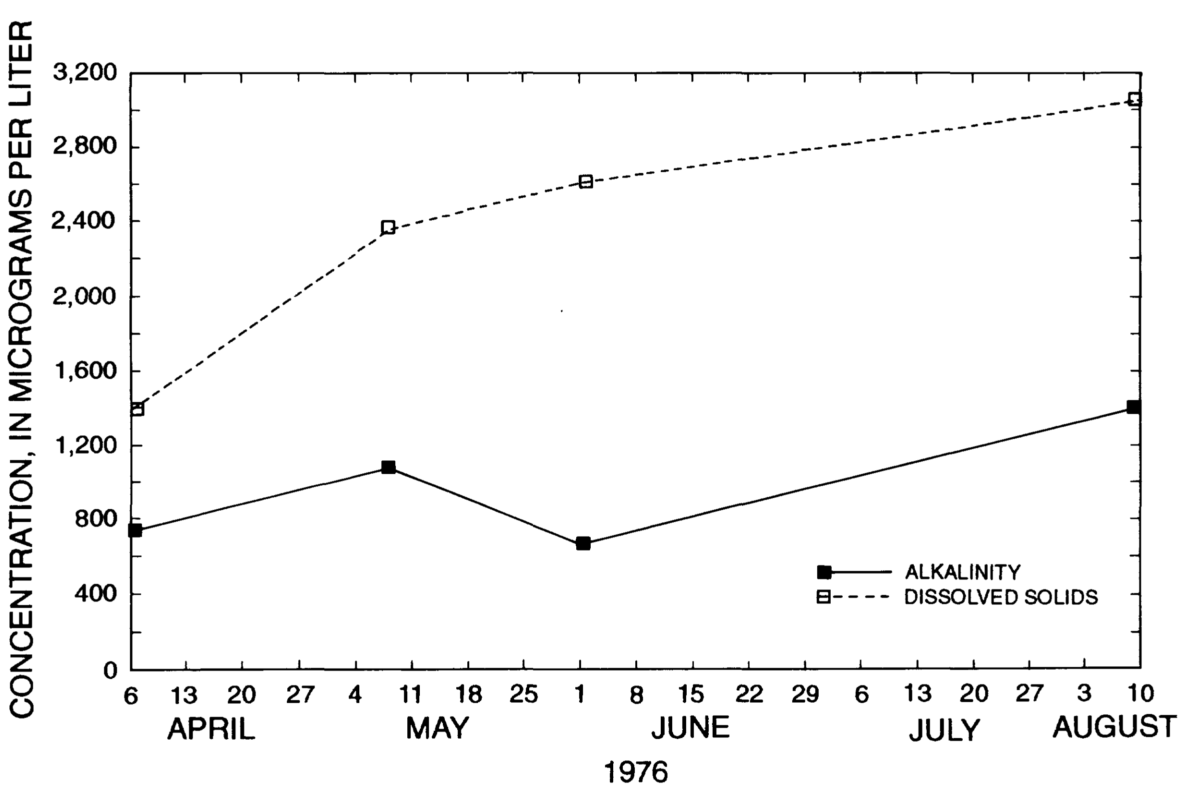

Figure 28.--Concentrations of alkalinity and dissolved solids in water from well 3, April through August 1976.

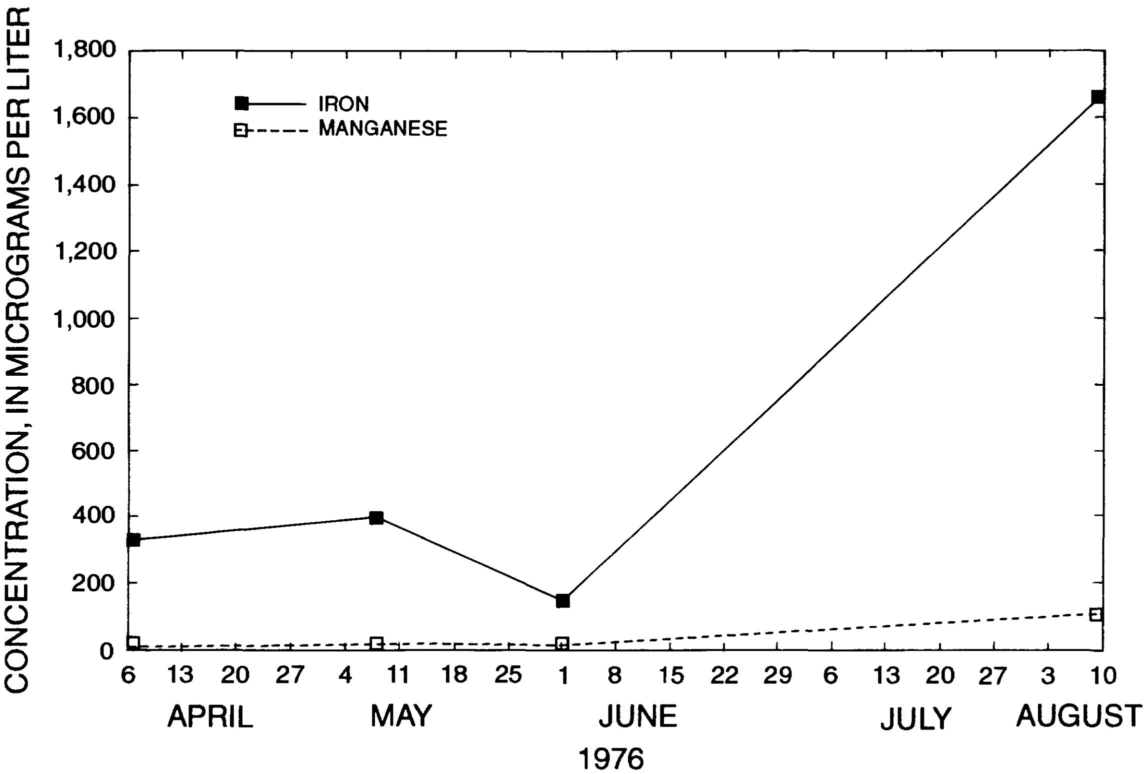

Figure 29.--Concentrations of dissolved iron and manganese in water from well 3, April through August 1976.

SUMMARY

The primary source of water supply for the city of Welch and the communities of Hemphill and Capels in McDowell County, W. Va., is from abandoned coal mines in the Pocahontas Nos. 3 and 4 seams. These mines, operated as the Exeter Mines, were abandoned in 1949.

Precipitation infiltration, inflow of surface water from the Tug Fork, and inflow of ground water from nearby mines and overlying strata (through fractures and uncased wells and shafts) are likely sources of recharges to the Exeter Mines. Rates of withdrawal during the study period ranged from 1.6 to 1.8 Mgal/d, whereas the maximum withdrawal rate needed to keep the mines dry during active mining was 1.0 Mgal/d. This increase in withdrawal rate indicates that recharge to the mines has increased since active mining. The increased recharge to the mines probably is because of increased infiltration rates and inflow from nearby mines.

The combined void space created by mining in the Pocahontas Nos. 3 and 4 seams could contain about 3.1×10^9 gal of water. Although subsidence fracturing and roof falls could have decreased void space in the mines, the corresponding increase in void spaces in the overburden could result in a combined volume nearly equal to the volume of coal that was removed in mining. Some additional storage is present in the voids formed by natural fractures and intergranular spaces in the rock that overlies the mine.

Water levels in the mines were monitored from July 1987 through September 1989. From October 1987 through April 1988, water levels in the mines rose more than 50 ft. This rise in water levels was associated with the abandonment and subsequent flooding of nearby mines in the Pocahontas Nos. 3 and 4 coal seams. Similarities in water-level fluctuations in wells that tap mines in the Pocahontas No. 4 coal seam in various areas indicate a large degree of hydraulic connection. Under hydrologic conditions present during the study, the Exeter Mines are capable of supplying water for Welch and the communities of Hemphill and Capels, even during periods of drought. On the basis of estimates of water use from July 1987 through July 1989, the volume of water stored in the Exeter Mines is about four times the combined annual water requirements of Welch, Hemphill, and Capels. Dewatering activities resulting from reopening abandoned adjacent mines or opening new mines adjacent to the Exeter Mines, however, could significantly reduce the availability of water in the mines.

The quality of water from the Exeter Mines changed when water levels rose and included increases in concentrations of sodium and chloride and decreases in concentrations of calcium and sulfate. The changes in water quality were largest in water from the coal shaft. The changes in water quality probably were associated with increased residence time of the mine water and decreased recharge from the Tug Fork. The increase in residence time probably resulted when nearby mines in the Pocahontas Nos. 3 and 4 coal seams filled with water, water levels rose higher than those in the Exeter mines, and the flow of water from the Exeter Mines to these mines ceased. The chemical quality of water from the coal shaft changed when Welch also began to use these mines for water supply. The resulting decrease in residence time of water in the mines and the increase in inflow of water from the Tug Fork caused increases in calcium, magnesium, and sulfate concentrations and decreases in sodium and chloride concentrations.

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
	Volume	
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Mass	
ton, short	0.9072	megagram

Water temperature, specific conductance, chemical concentration, and other chemical and physical properties of constituents (such as density, sorption, and vapor pressure) are given in metric units. Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

$$^{o}F = 1.8(^{o}C) + 32$$

Chemical concentration is expressed in milligrams per liter (mg/L) and micrograms per liter (µg/L).

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.